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A REPORT OF RESEARCH ON DETECTION OF DECEPTION

Performed by

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September 15, 1952

D. G. Ellson
Project Director

FOREWORD

A number of people have cooperated in the research reported here and it would be difficult to assign sole credit or responsibility for any part of the work to any one of them. However, there has of course been division of labor according to the special qualifications and interests of each.

Professor R. C. Davis carried most of the load where knowledge of physiological responses and methods of recording and experimenting upon them was necessary. The statistical knowledge of Dr. C. J. Burke was applied to the design of major experiments and the less routine analyses of results. Dr. I. J. Saltzman organized and directed much of the actual experimentation. Captain D. L. Kooken, chairman of the Indiana University Department of Police Administration, applied his experience and knowledge of lie detection as it is practiced to keep the feet of the rest of us somewhere near the ground. Most of the daily grind of running subjects, calibrating apparatus, and other necessary routines of research fell to four graduate students, Richard Atkinson, Harry Madison, Stanley Ratner, and Marvin Dotambol.

No less important is the work of the data analysis staff, too large to mention individually, whose detailed work of measuring thousands of responses and manipulating still more thousands of numbers is represented (in one sense, inadequately) by a few summary tables and graphs.

The construction of the electronic equipment for these studies has been the work of the Electronics Department of Indiana University. The solution of many of the technical problems encountered has come from Mr. G. F. Siddons and Mr. Gerald Stout of that department, and the basic design of some of the instruments was developed by them.

The last of the Indiana University staff to be mentioned is Mrs. Virginia Herron, who went far beyond routine requirements in preparing this report for reproduction.

Two groups outside Indiana University contributed to this research. Chapter X briefly summarizes some of the exploratory work on eye movements as indicators of deception carried out by Dr. James Calvin and Mr. Ernest Meyers of the Department of Psychology, University of Kentucky. Other exploratory investigations which have not been reported were done by Dr. William A. Livingston at the Department of Psychology, Butler University.

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CHAPTER I

INTRODUCTION

The aim of this research has been to investigate techniques for the detection of deception in which the contribution of the human operator to the administration of questions and the interpretation of response records is reduced to a minimum and repeatable routine. As far as possible these techniques of administration were selected in such a way that the relevant measures of the responses of the persons being examined could be converted to unambiguous scores and analysed singly or in combination by available types of automatic equipment. When this is done it is possible to measure the success of detection of deception which is attributable to the techniques rather than to the unique skills of the particular operators who interpret the records.

The research has not been limited to the more or less "standard" response variables recorded by the several varieties of Polygraph now in use: the physiological and psychological research literature and other sources have been examined for suggestions of other promising response variables, including many which were unknown or unmeasurable 20 or 30 years ago when most of the original research on "lie detection" was being performed. This broadening of the investigation together with the requirement that response measures be objective produces a tremendous increase in the number of variables which might be investigated. This means that only a sample (but a known one) of possible response variables can be examined. Strictly speaking, therefore, negative results in the present study would mean only that the particular sample of variables examined was not useful for the detection of deception and would not imply that other variables examined with the detail required for objectivity would be ineffective. Positive results, of course, apply only to the specific variables included in the validating experiments.

The selection of variables investigated on the final experiments of the present study was based on the examination of reports of previous work, supplemented by a number of exploratory studies designed to provide additional information concerning operating techniques and response variables. Some of these were informal studies utilizing a very few subjects which provided information suggesting modifications of apparatus, procedures, or response measures. Other exploratory studies were sufficiently complete to merit reporting. One factor determining the nature of these studies was the order in which various units of the experimental apparatus became available.

The report conveniently divides into two parts. Part I contains reports of the more complete exploratory studies mentioned above, in most of which a single response, such as the g.s.r., muscle action potentials, or eye movements was examined in relation to deception. Part II contains two related major experiments in which a number of response variables were measured simultaneously and discussion of the physiological and psychological background which influenced the choice of variables investigated in these experiments. In the first experiment the extent to which each variable was related to deception was determined separately. In addition, a treatment of the data which we have called *discriminant analysis* was applied in order to determine an optimum weighting of the variables in combination. In the second experiment the procedure was duplicated with a new group of subjects (and an increased number of repetitions of critical questions) in order to validate the weights determined in the first.

PART I

EXPLORATORY STUDIES

CHAPTER II

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION WITH THE GALVANIC SKIN REFLEX AS THE SOLE INDICATOR: I. ACCURACY OF DETECTION AND THE EFFECT OF REPETITION

Statement of the Problem

Most commercial lie-detectors measure two or three responses concurrently. One of the responses usually measured is the galvanic skin reflex. For several reasons this response appears to be admirably suited for use in the lie-detection situation where a series of questions is employed. (1) It is a relatively involuntary response; (2) it can be readily detected and measured; (3) its reaction time and its duration are conveniently short; and (4) complete adaptation of the response does not occur very rapidly.

Since the galvanic skin reflex (hereafter abbreviated g.s.r.) is frequently used in actual lie-detection work, information about the validity and reliability of the response as an indicator should be had. To be useful as an indicator of lying, the g.s.r., when a lying response is made, must be reliably different from the g.s.r. when a truthful response is made. The purpose of this study, then, was, first, to find out whether the g.s.r. meets the requirements of a useful indicator. Specifically, these questions were asked: Is the g.s.r. larger when a subject tells a lie than when he tells the truth? Secondly, how is the relationship between the size of the g.s.r. and the truthfulness of response affected by repetition of the lie-detection procedure?

Apparatus and Subjects

The apparatus was a commercial lie-detector manufactured by the B and W Associates, Michigan City, and called an Electronic Psychometer. The circuit for this instrument is unavailable, but some rough tests with an artificial subject indicate that its readings are not badly distorted so long as the subject's resistance is in the same region. The error would be least, therefore, in comparisons of within-sitting variations in the same subject. This is the sort of comparison made in the present studies. Ten Indiana University undergraduates served as the subjects in this experiment.

Procedure

Each subject was given a pencil and a small sheet of paper on which were listed the first six months of the year. He was asked to circle any one of the six months and to turn the paper over. The experimenter did not know which of the months had been circled. The subject was then informed that with the aid of the galvanometer the experimenter was going to try to discover which of the months had been circled. He was told that questions would be asked in the form: "Is it January, is it March, is it May?" He was instructed to answer "no" to each question. It was pointed out to the subject that in answering each question with "no", he would be answering truthfully on five of the questions and lying on one of them.

The subject was seated and an electrode was attached to each of the index fingers. He was asked to sit as quietly as possible. The experimenter sat behind the subject so that the subject could see neither the experimenter nor the galvanometer. The questions were asked at a rate of approximately one every twenty seconds. This allowed sufficient time for the galvanometer needle to return to pre-question level following each response. The experimenter recorded the maximum needle deflection following each question and answer to the nearest quarter of a scale unit. Each question was asked five times in an order which was random, except that no question was asked a second time before all questions had been asked once, etc. Each block of six questions constituted one trial. There were no rest intervals between trials.

After the thirty questions had been asked, the subject was allowed a five minute rest period. He was then required to repeat the whole procedure with a month which he selected from the last six months of the year. These first five trials of thirty questions with one month constituted one run; the second five trials with another month, a second run.

Results

Following the collection of the data, the experimenter computed the mean deflection size for each month for each of the experimental runs. The month with the largest mean deflection on each run will subsequently be referred to as the "detected" month. The month that the subject had circled was named the "selected" month. The degree of success in selecting the lying response from among the several truthful responses was indicated by the number of times the detected and the selected months were the same. If the largest mean deflection occurred with more than one month, no month was designated as the detected month. The results of each of the runs are as follows. On the first run, for eight of the ten subjects, the selected and the detected months were the same. For one of the two subjects where this was not the case, the largest mean deflection was obtained with two months, so no detected month was designated. One of those two months was the selected month. For the other subject whose detected and selected months were not the same, the selected month showed the second largest mean deflection. For all ten subjects on the first run the mean g.s.r. for the selected month was larger than the combined mean for all other months.

On the second run, for seven of the ten subjects the detected and selected months were the same. Of the three subjects where this was not the case, two were the subjects whose detected and selected months were different on the first run. The selected month showed the second largest g.s.r. for two of these three subjects. The selected month showed the smallest g.s.r. for the third subject. Except for this last subject, the selected month for all subjects showed a larger mean g.s.r. than the combined mean g.s.r. of all other months.

On the basis of chance alone, we would expect the selected and detected months to be the same in approximately 17% of the cases. The experimental results show that they were the same for 80% of the subjects on the first run and for 70% of the subjects on the second run.

For all subjects the selection of the detected month was made on the basis of the mean of all five trials. Table I indicates the percent of

TABLE I

THE PERCENT OF SUCCESSFUL DETECTIONS
WITH DIFFERENT NUMBERS OF TRIALS

Run	1st trial only	Mean of 1st two trials	Mean of 1st three trials	Mean of 1st four trials	Mean of all five trials
1.	60	80	80	80	80
2.	70	60	50	60	70

successes that would be obtained if only the scores from the first trial were used. Also indicated are percents of successes that would be obtained if the means of the first two, the first three, the first four, and all five trials are used.

Discussion

The first aim of this study was to find out how successfully a lying response can be selected from among several truthful responses with the amplitude of the g.s.r. as the only indicator. This experimental situation is obviously different from the typical lie-detection situation where the object is to discover whether or not a particular response is a lying response. In the experimental situation, the experimenter knows that one, and only one, of the six responses is a lying response. In actual lie-detection work, the operator faces a differently structured situation. None of the responses may be lying responses. Nevertheless, the experimental data are relevant for actual lie-detection. If the experimenter can identify the lying response with a large majority of the subjects, it means that the g.s.r. is usually larger when a lying response is made than when a truthful response is made. The operator in the actual lie-detection situation, then, could be advised to use the g.s.r. as an indicator. If, on the other hand, there is no relationship between the size of the g.s.r. and the truthfulness of a response, then it perhaps would not be profitable to use the g.s.r. as an indicator.

The results of the study indicate that selections of the lying response can be made with much better than chance success. In other words, the g.s.r. is usually larger when a subject tells a lie than when he tells the truth. On the basis of these results, then, we cannot say that it is inadvisable to use the g.s.r. as an indicator of lying.

Since the g.s.r. for the lying response was not the largest g.s.r. for all of the subjects, it must be asserted that the amplitude of the g.s.r. is certainly not an infallible indicator of lying. It is conceivable that there is a population of individuals for which the g.s.r. is not a suitable indicator. From our results this population appears to be smaller than the population of individuals for which the g.s.r. may be a suitable indicator. The findings of the second run of this experiment may be interpreted to support this notion that individuals fall into one or the other of two groups on the basis of their g.s.r. Of the three subjects whose largest g.s.r. was not obtained following the lying response on the second run, two were the same subjects with whom the same thing was found on the first run. With only one subject, then, was the largest g.s.r. not found with the lying response on the second run after it had previously been found with the lying response on the first run. These results suggest that the g.s.r. consistently identifies or fails to identify the lying response in a given individual. More data will have to be obtained to determine whether consistency of this sort is accidental or typical. If this notion of two populations turns out to be correct, it will be of great practical value to know in which population an individual belongs before the g.s.r. is used as an indicator with that individual.

Little effect of one repetition of the procedure on the success of selecting the lying response was found. The percent of correct identifications dropped slightly from 80% to 70%. Just what effect additional repetitions of the procedure might have cannot be stated without further experimentation. As for the effect of repeating the questions within one run, although the difference obtained between our first trial and the second is not reliable, it appears that on the first run, at least two repetitions are advisable. Further repetitions had no effect on the success of detection. The picture is not so clear on the second run, where no consistent trend appears from trial to trial.

Summary and Conclusions

Ten Indiana University undergraduates served as subjects in this experiment. The subjects selected a month from the first six months of the year and then were asked questions about the months. The subjects were instructed to answer each of the questions in the negative. The questions were asked at a rate of about one every twenty seconds and were phrased so that the subjects answered truthfully on all of the questions but one. Six different questions were asked and they were repeated five times in a quasi-random order. The size of the galvanic skin reflex following each question and answer was recorded. After a five minute rest the procedure was repeated with a month selected from the second six months of the year. The results were as follows: with eight of the subjects on the first run and with seven of the subjects on the second run the largest mean galvanic skin reflex followed the lying responses. It is concluded that: (1) the galvanic skin reflex is probably a suitable indicator of lying for a large population of individuals; (2) it is probably not a suitable indicator for a different, smaller population of individuals; and (3) one repetition of the detection procedure does not noticeably affect the success of the g.s.r. as an indicator.

CHAPTER III

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION WITH THE GALVANIC SKIN REFLEX AS THE SOLE INDICATOR. II. EFFECTS OF KNOWLEDGE OF SUCCESS OR FAILURE OF DETECTION UPON SUBSEQUENT SUCCESS OF DETECTION

Statement of the Problem

In our first investigation of the galvanic skin reflex (hereafter abbreviated g.s.r.) as an indicator of lying responses, it was found that when six similar verbal responses are made in a situation where one of the responses is a lying response and the other five are truthful responses, the lying response can be identified with much better than chance success. The lying response was correctly identified on the basis of the size of the g.s.r. with eight of the ten subjects used in the study. It was further discovered that when the detection procedure was repeated, the number of failures to detect the lying response increased from two to three.

In the above mentioned study, the subjects were not told before the repetition of the procedure whether the first attempt at detection had been successful. Under these conditions (with the subjects ignorant of the results of the first attempt) the g.s.r. failed to indicate the lying response with only one of the eight subjects with whom it previously had successfully indicated the lying response. In the typical lie-detection situation, however, when there is occasion to repeat the procedure, the subject usually knows whether or not the first attempt was successful. As a matter of fact, it is often the practice of lie-detector operators to make a preliminary run with non-relevant material with the express purpose of convincing the "subject" that the apparatus does work, that is, that the lying response can be identified. Often the operator has the subject select a card from a deck of playing cards; then, with the subject instructed to lie about the card, he proceeds to identify the lying response and thereby the card. The assumption underlying this kind of practice must be that convincing a subject that the lie-detector works, makes it more likely that the lie-detector will work. There are no experimental data to support or refute this assumption. The present study was designed to provide such data. Specifically, this question was asked: what effect does a subject's knowledge of the success of an attempt to detect one lie have upon the success of a second attempt with that subject? It was designed to provide information about the effects on the success of a second lie-detection attempt of (1) revealing to the subject, just before the beginning of the second attempt, that a successful first attempt had been made, and (2) revealing to the subject just before the beginning of the second attempt, that the first attempt had been unsuccessful.

In addition to providing us with some data on the effects of giving information on the success of a previous attempt at detection on a subsequent attempt, this experiment also serves to provide additional data on the adequacy of the g.s.r. as an indicator of lying response.

Apparatus and Subjects

The apparatus was the same B and W Associate's lie-detector used in our first study. Twenty-three Indiana University undergraduates, eleven in one group and twelve in another, served as the subjects in this study.

Procedure

The subjects were assigned to either one or the other of two groups in the order of their appearance. The initial treatment of the subjects in both groups was the same. Each subject was given a pencil and a small sheet of paper on which were listed the first six months of the year. He was asked to circle any one of the six months and to turn the paper over. The experimenter did not know which of the months had been circled. The subject was then informed that with the aid of the galvanometer the experimenter was going to try to discover which one of the months had been circled. He was told that questions would be asked in the form: "Is it February, is it April, is it January, etc.?" He was instructed to answer "no" to each question. It was pointed out to the subject that by answering each question with "no", he would be answering truthfully to five of the questions and lying on one of them.

The subject was seated and an electrode was attached to each of his index fingers. He was asked to sit as quietly as possible. The experimenter sat behind the subject so that the subject could see neither the experimenter nor the galvanometer. The questions were asked at a rate of approximately one every twenty seconds, allowing sufficient time for the galvanometer needle to return to pre-question level following each response. The experimenter recorded the maximum needle deflection following each question and answer to the nearest quarter of a scale unit. Each question was asked five times in an order which was random except that no question was asked a second time until all questions had been asked once, etc. Each block of six questions constituted one trial. There were no rest intervals between successive trials.

After the thirty questions had been asked, the subject was allowed a five minute rest period. During the rest period, the experimenter computed the mean deflection size for each of the months. At the close of the rest period, the experimenter announced to the subject the month which he said he believed the subject had circled. It was at this point that the procedure for the two groups differed. For the subjects in Group I, the month that was announced was the one which the experimenter believed the subject had circled -- the month with the largest mean g.s.r. For the subjects in Group II, the month announced was a month which the experimenter believed the subject had not circled -- the month with the smallest mean g.s.r. When the announced month and the month that had been circled were the same, the fact that a successful detection had been made was pointed out to the subject. Similarly, when the announced month and the month that had been circled were not the same, the fact that the attempt at detection had not been successful was pointed out to the subject. After the statement by the experimenter about the success or failure of the detection attempt, all subjects in both groups were required to repeat the procedure with another month which the subject selected from the last six months of the year. After the second series of five trials (thirty questions), the subjects were dismissed. The experimenter then computed the mean g.s.r. for each of these months. The first series of five trials constituted the first run; the second series of five trials constituted the second run.

Results

The results of this study together with those from the previous study are contained in Table I. With regard to the adequacy of the g.s.r. as an

TABLE I

PER CENTS OF SUCCESSFUL AND UNSUCCESSFUL DETECTIONS ON 1st AND 2nd RUNS FOR ALL GROUPS OF SUBJECTS

Groups	Successes on 1st run	Successes on 2nd run	Successes on 1st run which are successes on 2nd run	Failures on 1st run which are failures on 2nd run
I informed correctly	9/11 = 82%	3/11 = 27%	3/9 = 33%	2/2 = 100%
II misinformed	9/12 = 75%	10/12 = 83%	8/9 = 89%	1/3 = 33%
III no information (from previous study)	8/10 = 80%	7/10 = 70%	7/8 = 88%	2/2 = 100%

indicator of lying, it was found that on the first run nine of the eleven subjects in Group I and nine of the twelve subjects in Group II showed their largest mean g.s.r. on the lying response. This was the case with eight of the ten subjects from the first study. The percent of subjects in each group where the largest mean g.s.r. is associated with the lying response is similar for all three groups: 82%, 75% and 80%. The g.s.r. is a successful indicator of lying with 79% of the subjects from the three groups combined.

The percent of subjects where the largest mean g.s.r. is associated with the lying response on the second run is noticeably different in each group: 27% and 83% for the two groups in this experiment, and 70% for the group from the previous study. Perhaps a more meaningful comparison of the three groups on the second run is obtained when we look at the success of the g.s.r. in indicating the lying response on the second run with only those subjects whose lying responses on the first run had been correctly identified. The group of subjects that was ignorant of the success or failure of the first detection (Group III) and the group of subjects which was misinformed and led to believe that the first detection had been a failure (Group II), both show about the same percent of correct detections: 88% and 89%, respectively. With only one of eight subjects in Group III and one of nine in Group II were the lying responses undetected on the second run after they had been successfully detected on the first run. However, with only three of the nine subjects of Group I who had been correctly informed that a successful detection had been made on the first run, were successful detections made on the second run.

The table also shows the results for the subjects whose lying responses do not show the maximum g.s.r. With only two of these seven subjects with whom incorrect detections were made on the first run, were correct detections made on the second run.

The number of successful detections based on the scores from the first trial, the means of the first two, the first three, the first four, and all five trials are shown in Table II. In all instances the greatest number of

TABLE II

THE PERCENT OF SUCCESSFUL DETECTIONS WITH DIFFERENT NUMBERS OF TRIALS

Groups	Run	1st trial only	Mean of 1st two trials	Mean of 1st three trials	Mean of 1st four trials	Mean of all five trials
I	1.	7/11 = 64%	7/11 = 64%	8/11 = 73%	9/11 = 82%	9/11 = 82%
	2.	4/11 = 36%	3/11 = 27%	4/11 = 36%	4/11 = 36%	3/11 = 27%
II	1.	3/12 = 25%	5/12 = 42%	6/12 = 50%	8/12 = 67%	9/12 = 75%
	2.	4/12 = 33%	10/12 = 83%	11/12 = 92%	9/12 = 75%	10/12 = 83%
III	1.	6/10 = 60%	8/10 = 80%	8/10 = 80%	8/10 = 80%	8/10 = 80%
	2.	7/10 = 70%	6/10 = 60%	5/10 = 50%	6/10 = 60%	7/10 = 70%

successes, on the first run, is obtained when the mean of all five trials is used. On the second run, no consistent picture is obtained.

Discussion

Combining the results of this and the previous study, we find that the g.s.r. was successful in 26 of 33 attempts, or in 79% of the cases. On a chance basis we should expect the largest mean g.s.r. to be associated with the lying response in approximately 17% of the cases -- five or six successes in 33 attempts. The obtained results indicate that with 79% of the population used in these two studies, the g.s.r. is a successful indicator of lying responses.

The data of these two studies combined indicate that:

(1) Success on one attempt at detection with the g.s.r. alone is very likely to be followed by a second, unless the subject is told that the first attempt was successful, and

(2) Failure on a first attempt is likely to be followed by failure on a second, regardless of information given to the subject.

The subjects in these experiments were college students. In this population it appears that there are some individuals for whom the g.s.r. is not a suitable indicator. Since this population appears to be much smaller than the population for which the g.s.r. is effective, these results may be considered encouraging and suggest follow-up studies on other and larger populations examining other laboratory lying situations as well as non-laboratory lying situations. If the results obtained in these studies can be duplicated with other, larger populations, then a pre-lie-detection test utilizing the g.s.r. might be valuable as standard procedure to determine whether or not the g.s.r. should be used with specific individuals in actual lie-detection situations.

Summary and Conclusions

Twenty-three Indiana University undergraduates served as subjects in this experiment. All 23 subjects selected a month from the first six months of the year and then were asked questions about the months. The subjects were instructed to answer each of the questions in the negative. The questions were asked at a rate of one every 20 seconds and were phrased so that the subjects answered truthfully on all of the questions but one. Six different questions were asked and they were repeated five times in a quasi-random order. The size of the galvanic skin reflex following each question and answer was recorded. After a five minute rest 9 of the 11 subjects in Group I were told that the month which they had selected had been detected by the experimenter. Nine of the 12 subjects in Group II were told that the month which they had selected had not been detected by the experimenter. The procedure was then repeated with a month selected from the second six months of the year. The results show that success on one attempt at the detection with the g.s.r. alone is very likely to be followed by a second success, unless the subject is told that the first attempt was successful.

CHAPTER IV

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION WITH THE GALVANIC SKIN REFLEX AS THE SOLE INDICATOR: III. THE NATURE OF THE RESPONSE TO THE STIMULUS QUESTIONS

The procedure that was used in our first two studies to determine the usefulness of the galvanic skin reflex (hereafter abbreviated g.s.r.) as an indicator of lying responses was one which required the subjects to answer all the questions which were asked by the experimenter with the same response, "no". The experimental situation was designed and the questions were phrased so that the answers to five of six questions were truthful answers. The answer to one of the six questions was a lying answer. The decision to follow this procedure was an arbitrary one. However, the choice was apparently a fortunate one, since a large majority of the detections were successful.

The present study represents a first attempt at getting an answer to the problem of the importance of the response itself in detecting lying responses. Four different kinds of response situations were selected for study. One situation duplicated the procedure that was found to be successful in our first studies: the subjects were required to answer all questions in the negative, thereby lying on only one of the four questions and telling the truth on the other three. Another situation required the subjects to answer all four questions in the affirmative, thereby lying on three of the four questions and telling the truth on one of them. A third situation required the subjects to remain silent when the questions were asked and a fourth situation allowed the subjects to answer the questions as they chose with either "yes" or "no". The experiment was designed to provide a means for evaluating the role of the response in the lie-detection situation.

Apparatus and Subjects

The apparatus was the ONR laboratory galvanometer described elsewhere (Davis) in conjunction with an Esterline-Angus recorder. The subjects were eight Indiana University undergraduates.

Procedure

Each of the response situations was assigned a letter as follows: A: "no" to each question; B: "no" or "yes" at the subject's discretion; C: "yes" to each question; and D: no responses at all to the questions. A four by four Latin Square Design was used with one replication. The following squares were used:

Square I

Subjects	Order 1st	2nd	3rd	4th
1	B	D	A	C
2	D	A	C	B
3	C	B	D	A
4	A	C	B	D

Square II

Subjects	Order 1st	2nd	3rd	4th
5	D	B	A	C
6	C	D	B	A
7	A	C	D	B
8	B	A	C	D

The subjects were assigned numbers in the order of their appearance for the experiment. Each subject was seated in a comfortable armchair and was told to relax for several minutes. Then an electrode was attached to each of his palms. Next the subject was shown a sheet of paper with the months of the year written in order in three groups of four months each. The subject was asked to indicate which group of four months included his birth month, without revealing to the experimenter which one of the four months was his birth month. The following instructions were then read to the subject:

> By means of this apparatus I am going to try to determine the month of your birth. Your job is to keep me from detecting your birth month. We are going to go over the list of four months several times under several conditions and then I will tell you the month which I think is your birth month. During the questioning it is very important that you do not move. Also, I would like you to keep your eyes closed during the questioning. Any questions?

The subject was allowed to relax again for about one minute while the experimenter adjusted the apparatus. Then the instructions for the first kind of response were given to the subject. The different orders in which the four response situations were used with the different subjects were dictated by the Latin Square.

After the subject had received instructions about the kind of response he was to make to the questions, the experimentation was begun. The questions were always asked in the form: "Were you born in ________?" An inter-question interval of approximately 30 seconds was used. Each question was asked twice, in an order which was random except that no question was asked a second time before all four questions had been asked once. Each block of four questions constituted one trial. There was no break between the two trials with a given response situation. After the second trial with a given response situation the subject was asked to open his eyes and he was instructed on the next response situation. An interval of approximately two minutes elapsed between successive response situations. When the last response situation was completed, the experimenter made a guess about the subject's birth month and then found out the actual birth month by asking the subject.

Results

The mean g.s.r. for each of the four questions under each of the four response conditions was computed. On the basis of chance factors alone, we might expect that with each response situation the largest mean g.s.r. would occur with the birth month question in one out of four instances. In our experimental situation, then, we might expect, by chance, to find the largest mean g.s.r. associated with the birth month for two of the eight subjects under each of the conditions. The results of the study show that with only one of the four response conditions studied was the number of such occurrences greater than two. This occurred when the subjects were required to reply in the negative to all of the questions, thereby lying only on the birth month question. Four of the eight subjects, when run under these conditions of responding, showed their highest mean g.s.r. on the birth month question. We cannot reject the hypothesis that this was a chance result, however ($p = .126$). When the subjects were required to respond in the affirmative to all the questions, thereby lying on all questions except the birth month question, only two of the eight subjects showed their highest mean g.s.r. on the birth month question. Since, under these conditions, the response to the birth month question was the only truthful response, it might be expected that the smallest mean g.s.r., rather than the largest, would occur on the birth month question. The results show that with none of the subjects did the smallest mean g.s.r. occur with the birth month question. When the subjects were required to remain silent during the questioning, it was found that with only one of the eight subjects was the largest mean g.s.r. associated with the birth month question. And when the subjects, at their own discretion, replied with either "no" or "yes", it was found that with only two of the eight subjects did the largest mean g.s.r. occur with the birth month question. Since no record of the verbal responses was taken it is not known on which of the questions the subjects lied or told the truth under those conditions of responding.

Discussion

In our previous studies with the g.s.r. the procedure that was adopted required the subjects to answer all questions with "no", so that only one lying response and several truthful responses were made. With this procedure, detections of the lying responses were made with much better than chance success -- 79% successful detections. These studies did not indicate, however, whether the number of successes was affected by the response that the subjects were required to make. The present study seems to indicate, though not conclusively, that the kind of response was an important factor in producing the high proportion of successful detections. In the present study better than chance results were obtained, although not significantly better, only for the procedure requiring the same response as in the earlier studies. It appears that in order to identify with better than chance success the month that the subjects select, it is necessary that the subjects reply verbally to the questions as they are asked. And the situation should be one where all responses to questions are truthful responses except the responses about the specific month selected.

In our first studies with the g.s.r., the lying response was identified in 79% of the cases When the same response required in those studies was used in this study, the lying responses were detected in only 50% of the cases. The smaller percent of successful detections in the present study was to be expected since it included only one repetition of each question. Detections in the former studies were based on five trials. If detections had been made on the basis of only two trials in the former studies, the percent of successful detections would have been 62%.

Another factor which may have predisposed toward fewer successes in the present investigation is the use of each subject as his own control. Each subject participated under each of the experimental response conditions which may have reduced the number of successful detections.

CHAPTER V

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION: A PRELIMINARY INVESTIGATION OF CARDIO-VASCULAR RESPONSES

Introduction

This study was not primarily concerned with the detection of deception. It was, rather, an examination of some cardio-vascular responses in several non-lying situations. It was hoped, however, that the study would provide us with information on the kind of responses we might expect in the lying situation.

The experiment was designed to provide a comparison of the cardio-vascular responses under three different conditions: 1) an extended rest interval, 2) a "neutral" questioning period, and 3) a mild stress situation. The cardio-vascular responses that were measured were: 1) heart rate, 2) heart-pulse lag, 3) blood volume changes in the index finger, 4) changes in skin temperature, and 5) blood pressure. The apparatus for measuring these responses is described in the section on methods of measuring circulatory variables.

Since this was the first of the cardio-vascular studies, (two earlier attempts were discontinued because of necessary procedural changes) the experimenters were not yet thoroughly familiar with the apparatus, the equipment was not yet working perfectly, and the procedure was essentially untested. Consequently, a detailed analysis of the data was not considered advisable. The data were analyzed in sufficient detail, however, to provide suggestions for the subsequent investigations.

Procedure

Eighteen undergraduate men and women served as subjects in this experiment. Each subject was seated in the subject's chamber and while the various leads were being connected he was informed that the experimenter was interested in measuring some of his physiological responses. He was told that the experimenter would leave the room shortly and would communicate by means of the loud speaker and microphone which were mounted in the wall. The subject was told that after awhile he would be asked some questions which he was to answer out loud. He was asked to remain as motionless as possible during the experimental session. When the experimenter was sure that the subject was at ease and that the leads had been connected properly, he left the subject's chamber.

The three parts of the experimental procedure were as follows:
Rest: Three one minute records were made with two minute intervals separating the successive records. The subject was not informed when the records were being made. Each one minute record included three pressure cycles of the vascular occluding pump.

Neutral Questions: Two minutes after the last record, the recorder was turned on. After one complete pressure cycle, and immediately following the start of the second cycle, the experimenter asked over the loud speaker: "What is your first name?" The recording was continued until that cycle and the two following were completed. The recorder was then turned off for two minutes. Following the two minute wait, the recorder was turned on and after one complete cycle, as soon as the next cycle began, the experimenter asked: "How much are two and two?". The recording was continued until that cycle and the two following were completed.

Stress: After a two minute delay, the recorder was turned on, and at the beginning of the second pressure cycle the experimenter asked: "Do you feel an electric shock on your left hand?". The recording was continued uninterrupted for three cycles following this question. As soon as the next cycle began, the experimenter announced: "Don't move your left hand! We seem to have a bad connection and we don't want you to get shocked!". The recording continued for three more cycles before the recorder was turned off and the subject was released.

Results and Discussion

Heart rate: Several samples of the heart rate during the rest intervals were averaged for each of the subjects. (The records of only 15 of the 18 subjects were used, since the records of the three other subjects were incomplete.) Also samples of the heart rate were taken following the subjects' responses to the neutral questions and following the shock suggestions. A comparison of the heart rate under these three conditions revealed a slight slowing of the heart for most of the subjects during the neutral questioning period and a greater slowing during the shock threat. The average heart rate for all subjects was slowest for the shock threat situation, next slowest for the neutral questions and fastest for the rest intervals.

Heart-pulse lag: A comparison of the heart-pulse lag measured during each of the three conditions of our experiment revealed no consistent changes. Complete records, however, were obtained for only six of the 18 subjects.

Skin temperature and blood volume changes: The temperature changes on the tip of the left forefinger were not found to be consistently related to the experimental conditions. The records of 13 of the 18 subjects were used. The same absence of relation was found for blood volume changes, where the records of 14 of the subjects were used.

Blood pressure: No consistent effects of our conditions on the blood pressure measures were detected. It is likely that we did not find any effects because of the counteracting effects of local vasoconstriction. This matter is discussed in the section on methods of measuring circulatory variables.

It should be pointed out that this study was primarily exploratory. The results of the experiment were by no means considered final, but only suggestive.

Summary

Several cardio-vascular responses were examined under three experimental conditions: rest, neutral questioning, and mild stress. The most promising of the measures was the heart rate, which showed a deceleration in the stress situation.

CHAPTER VI

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION: FURTHER INVESTIGATION OF THE CARDIO-VASCULAR RESPONSES

Introduction

In our first study (See Chapter V) of the cardio-vascular responses, we compared the responses occurring under three different conditions: rest, neutral questioning, and mild stress. Of the several responses recorded, only one, the heart rate, was found to vary consistently with changes in the experimental conditions.

The present study is essentially a repetition of the earlier study with several modifications. In addition to answering some neutral questions, the subjects in the present study were required to commit a laboratory crime and then lie about it when questioned by the experimenter. They were also subjected to a stress situation early in the experimental procedure as well as at the end. The present study, then, enabled us to compare the cardio-vascular responses occurring during: 1) a rest interval, 2) two stress situations, 3) non-lying responses, and 4) lying responses.

The responses which were recorded in the present study were the same as those recorded in the previous study. In addition, however, new techniques for measuring the recorded responses were used. The responses recorded in this study were: heart rate, heart-pulse lag, blood volume changes in the index finger, changes in skin temperature, pulse height, and blood pressure.

Procedure

The subjects in this experiment were 44 undergraduate students. Each subject was told that the experiment was concerned with lie detection. He was then shown four sets of coins: ten nickels, five dimes, two quarters, and a fifty cent piece. A cover was placed over the coins and the subject was told:

> After I leave the room, I want you to take one of the sets of coins and put it in your pocket (or purse); then replace the cover over the remaining coins. When I return, do not tell me which coins you have taken. Later on I shall try to find out by asking you questions about the coins. If I am not successful, you may keep the coins that you have taken!

The experimenter left the room and returned after the subject had removed the coins. The subject was then seated at a table and the apparatus was connected. While the apparatus was being adjusted, the subject was informed that shortly he would be asked to read aloud, but that before he did any reading he was to sit quietly and relax. He was told that he would be notified when he was to begin reading. The reading matter was a page from a textbook, which was held in position at eye level by a clamp and stand located on the table in front of the subject. When the subject indicated that he understood the instructions, a pair of ear phones were placed on his head and a microphone was positioned on the table close to his mouth. The microphone and ear phones were connected to a modified tape-recorder which was wired so that the words spoken by the subject into the microphone returned through the ear phones after a delay of .2 seconds. The typical effect of the "delayed feed-back" on unsuspecting subjects is to disrupt their speech noticeably. It was used in the present study to produce an emotional or stress situation.

While the subject was resting, before he was asked to begin reading aloud, a one minute record of his responses was made. The recorder was then turned off and the subject was asked to begin reading. After the subject had been reading for approximately 30 seconds, the recorder was turned on and a one minute record of his responses was made. The subject was then told to stop reading, and after a two minute wait, a one minute record of his responses was made. The experimenter then reminded the subject of the fact that he had taken fifty cents from under the box. He was informed that the experimenter was going to leave the room and that he would communicate by means of the loud speaker and microphone which were located in the wall. The subject was told that he would be asked a series of questions which he was to answer out loud. The subject was told to answer all of the questions truthfully, except those questions which had to do with the particular coins he had taken. He was reminded that he would be permitted to keep the coins that he had taken if the experimenter was unable to discover from his responses which coins had been taken. The experimenter left the subject's room after he was certain that the subject understood the instructions.

After about a one minute delay the recorder was turned on and a series of 14 questions was asked. The questions were asked at a rate of one question a minute. Each question was asked immediately after the break in the pulse line which indicated that the mercury pressure was beginning to be applied to the finger. The questions that were asked were as follows:

1. Can you hear me?
2. Is today Sunday?
3. Did the light just go off?
4. Are you comfortable?
5. Did you take the nickels?
6. Did you take the fifty cent piece?
7. Are the quarters still under the box?
8. Did you take the dimes?
9. Are the nickels still under the box?
10. Are the dimes still under the box?
11. Did you take the quarters?
12. Is the fifty cent piece still under the box?
13. Do you feel an electric shock on your left hand?
14. Don't move your left hand! We seem to have a bad connection and don't want you to get shocked.

About one minute after the last question the recorder was turned off and the subject was removed from the apparatus. He was reassured about the shock threat situation and asked not to talk with other potential subjects about the experimental procedure.

Results and Discussion

Samples of each of the response measures were taken under each of the experimental conditions and averaged for all subjects. Analyses of variance indicated that two of our response measures discriminated between the experimental conditions. Since the results were for the most part negative, and since we used essentially the same measuring techniques as were used in Procedures 6 and 7, where they are described in detail, only a summary of the findings of this experiment will be presented here.

Heart Rate: The heart rate was found to vary significantly with the experimental conditions used in this experiment. The order for the conditions, from fastest to slowest heart rate was: feed-back, non-lie, lie and shock threat. Table I shows t-values and their corresponding probabilities.

TABLE I

SIGNIFICANCE OF DIFFERENCES IN HEART RATE

Conditions	t	P
Non-lie -- lie	2.50	.02
Lie -- shock	4.41	.01
Non-lie -- shock	6.91	.01
Feed-back -- non-lie	1.73	.10
Feed-back -- lie	4.22	.01
Feed-back -- shock	8.64	.01

Skin Temperature: No significant differences for skin temperature were found.

Blood Volume of Index Finger: No significant differences for blood volume were found.

Pulse Amplitude: The amplitude of the pulse was found to vary significantly with the experimental conditions. The order for the conditions, from largest to smallest pulse was: non-lie, shock threat, lie and feed-back. Table II shows the t-values and their corresponding probabilities.

TABLE II

SIGNIFICANCE OF DIFFERENCES IN PULSE AMPLITUDE

Conditions	t	P
Non-lie -- lie	2.99	.01
Lie -- shock	1.37	.10
Non-lie -- shock	1.63	.10
Feed-back -- non-lie	5.06	.01
Feed-back -- lie	8.06	.01
Feed-back -- shock	6.69	.01

Heart-pulse Lag: No significant differences for heart-pulse lag were found.

Blood Pressure: Due to local vaso-constriction, probably, no significant effects on blood pressure were found.

Summary

Several cardio-vascular responses were examined under several different conditions. The most promising measures for lie-detection were heart rate and pulse amplitude.

CHAPTER VII

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION WITH THE MUSCLE ACTION POTENTIALS AS THE SOLE INDICATOR: MUSCLE ACTION POTENTIALS TAKEN FROM OPPOSED MUSCLE GROUPS IN THE ARM UNDER "CONFLICT" AND "NON-CONFLICT" CONDITIONS

Statement of problem: This experiment was designed to look for characteristics of muscle action potentials from opposed muscle groups which distinguish situations involving motor conflict between the muscle groups from those in which conflict is absent. A simple means of trying to set up such conflict is described in the procedure.

Apparatus and procedure: The stimuli used in this experiment were four 8" x 4" opaque plastic cards displayed in a lighted exposure window of the same dimensions. The subjects were seated before the exposure window in a soundproof room and four stimulating situations were defined, one corresponding to each card, as follows:

Situation R: The displayed card had an X-mark on the subject's left and was blank on the subject's right.
Situation L: The displayed card had an X-mark on the subject's right and was blank on the subject's left.
Situation B: The displayed card had an X-mark on both sides.
Situation N: The displayed card was entirely blank.

Electrodes were attached to the flexor carpi radialis and extensor digitalis muscles of the right forearm, the S was seated at a small table where a shuttle key apparatus, with a ten-inch arm and a stationary "middle" position, was stationed. Both forearms were placed on the table and the shuttle key position was adjusted for the S's arm length. Four paired leads to a four-channel EMG recording unit were attached to the appropriate electrodes on the S's arm. The instructions given the subject are paraphrased below:

> "A series of cards will be presented in the exposure window; some cards will have an "X" on the right side and some will have an "X" on the left. Before each exposure, a tone will be sounded as a ready signal. Then the card will be exposed for a short interval. After the card has disappeared, push the key to the right if the "X" is on the left side of the card and push the key to the left if the "X" is on the right side of the card. When pushing the key, be sure the movement is made through the wrist. (Here the experimenter demonstrated the proper movement.) At all times remain as relaxed as possible, exercising a minimum of body activity."

With these instructions, we should anticipate a movement to the right in situation R, to the left in situation L. In situation B we might expect a tendency toward movement in both directions and in situation N, a tendency toward movement in neither. The anticipations in situations R and L are fairly certain; those in B and N, somewhat questionable.

After a sham trial checking the subject's ability to follow directions, the experimental room was closed and about five minutes later the stimulus cards were presented. Thirty trials were given and, for every S, the order in which the situations were presented was as follows: R, L, L, R, R, L, R, L, R, L, L, R, N, L, B, R, R, L, B, R, L, N, L, R, L, B, R, R, L, N. In this series, situations R and L each occur 12 times and situations B and N, 3 times. The first eight trials, in which situations R and L are each represented four times, were treated as training trials. The analysis is based on data obtained during the last 22 trials, the test trials of the experiment.

The intertrial procedure was the same for all subjects and all exposures. A tone signal whose duration was .185 seconds was sounded. After a three-second delay, the particular card selected for the trial was presented for four seconds. The time between trials varied around one minute, depending upon necessary adjustments of the EMG equipment. Seventeen students at Indiana University were run as subjects.

Results

If conflict occurs and is exhibited by activity in the opposed muscle groups, the increase in activity should manifest itself during the interval between the presentation of the stimulus card and the occurrence of the overt response. The maximum amplitude of the action potentials during this interval was recorded and analyzed. It was found not to distinguish reliably between situations B and N, which presumably involve conflict, and situations R and L, which do not. From the belief that reliable effects might be obscured by random changes in activity during the pre-stimulus interval, a more refined analysis, described below, was carried out (see also Chap. XX).

Four temporal intervals were taken in the records: (1) the two seconds immediately preceding the stimulus exposure, (2) the first two seconds of stimulus exposure, (3) the last two seconds of stimulus exposure, and (4) the interval from the end of stimulus exposure to the beginning of the response. The maximum action potential on each muscle during each period was read.

To ascertain whether the differentiation of the conflict situation for individual subjects can be made on the basis of these action potentials, a discriminant analysis was run to determine such weights for each of the eight readings as would provide maximum discriminability of situation B from situations R and L. From the discriminant analysis there results a single measure characterizing each individual in each situation. These measures are given in Table I.

We see from the data in Table I that it would be impossible to classify situations for individual subjects reliably even on the basis of the best discriminating variable. To probe the matter more deeply, we classify the subjects as follows:

TABLE I

RESULTS OF DISCRIMINANT ANALYSIS FOR INDIVIDUAL SUBJECTS

Subject \ Situation	R	L	B
1	72.1	55.2	65.1
2	67.2	45.6	67.3
3	53.5	76.6	79.1
4	95.2	-1.7	39.1
5	65.1	72.0	72.7
6	32.6	41.6	45.9
7	82.4	60.8	96.0
8	76.5	87.8	73.5
9	39.5	47.5	60.5
10	90.5	84.3	93.3
11	35.4	44.2	20.2
12	35.3	43.6	32.1
13	36.9	48.0	44.1
14	9.1	25.0	26.4
15	46.4	39.0	5.4
16	52.0	32.1	55.2
17	78.7	57.6	83.0

If the score in Table I for situation B is the largest of the three scores, a "+" is assigned; if it is the smallest, a "−" is assigned; if it is intermediate a "0" is assigned. In this way, we obtain the frequencies in Table II.

TABLE II

FREQUENCY DATA FROM DISCRIMINANT SCORES

Class	+	0	−	Total
Frequency	10	3	4	17

There is a preponderance of +'s in Table II which would arise less than 1/20 times by chance. Thus we may conclude that, although the discrimination is insufficiently powerful to be used with individual subjects, some discrimination seems to be present in an overall statistical sense.

Conclusions

On the basis of action potential records from opposed muscle groups, situations involving motor conflict differ statistically from those in which conflict is absent. In the experimental context described above, the differentiation was not sufficiently marked to permit reliable classification on an individual basis. This failure may be attributable to the large variability associated with action potential measures or it may reflect genuine individual differences in response. If this line of experimentation is continued, the problem of obtaining reliable measures from each individual subject must be faced.

CHAPTER VIII

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION WITH THE MUSCLE ACTION POTENTIALS AS THE SOLE INDICATOR: MUSCLE ACTION POTENTIALS TAKEN FROM OPPOSED MUSCLE GROUPS IN THE ARM DURING "LYING" AND "NON-LYING" MOVEMENTS OF THE ARM

Statement of the problem: The subject is placed in a situation with instructions to indicate the answers "yes" and "no" by pushing a shuttle key in one direction or the other. The key pushing necessitates a movement of the forearm which involves the activity of two opposed muscle groups. The situation is arranged so that the subject will sometimes, but not always, lie, and lying responses may involve motor conflict in which the opposed muscle groups act. The experiment is designed to test for such conflict and to inquire into the feasibility of using muscle action potentials in situations of this type to differentiate lying from non-lying responses.

Apparatus and procedure: The experimental arrangements are similar in many respects to those described in the experiment reported above; the major difference concerns the stimulus materials which, in this situation, provided the basis for lying and truth-telling in the experiment. The experimental arrangements and the recording of responses are identical with that of the previous study. Nineteen college students were run as subjects.

The subject was provided an opportunity to take fifty cents, in either nickels, dimes, quarters, or a half-dollar. Crucial questions presented visually during a subsequent interrogation concerned the denomination of the particular coins he had taken. He was instructed that he might keep the money if he successfully escaped detection. The equipment was calibrated during a series of innocuous questions.

Following this, a series of sixteen cards, containing the questions listed below were presented and the subject responded, according to the instructions given, with a "yes" or a "no" movement as indicated by the Y's and N's to the left of the questions.

Critical cards

Y Is the half-dollar package under its box?
N Did you take the fifty cent piece?
Y Is the quarter package under its box?
N Did you take quarters?
Y Is the dime package under its box?
N Did you take dimes?
Y Is the nickel package under its box?
N Did you take nickels?

Money cards

Y Is a dollar equal to one hundred cents?
Y Are there one hundred cents in a dollar?
N Is a dollar equal to ninety-nine cents?
N Is a dollar equal to ninety-seven cents?

General cards

Y Are you independent?
 Are you organized?
Y Are you the only child in your family?
 Do you have any brothers or sisters?
N Is your birthday on August 10?
 Is your birthday on April 3?
N Is your home in Detroit?
 Is your home in St. Louis?

The order of presentation of the cards was randomly varied for each subject within the following restrictions.

(1) Each block of four cards had two "critical" questions, one "money" question, and one "general" question.
(2) Two "critical" questions referring to the same coin never occurred in the same block.
(3) A (Y) "money" question within a block was always balanced by a (N) "general" question and vice versa.
(4) Successive blocks never had two (Y) "money" questions or two (Y) "general" questions and similarly for N questions.

Results

From the response records it was possible to read both response amplitudes and reaction times. Analysis of the response amplitude revealed no discriminative power. t-tests run on the data revealed that the reaction times gave 5%-level evidence of discriminating lies from truths, responses to critical cards from responses to others, and responses to money cards from responses to general cards. The critical cards were not discriminated from the money cards at this level. The mean values of the log reaction times in increasing order are on: (1) critical lying responses, (2) critical non-lying responses, (3) money card responses, and (4) general card responses.

These data on reaction times indicated the possible importance of the temporal order of events. With this in mind, the records obtained from the left side of the arm were subjected to a further analysis. Six temporal intervals (pre-stimulus, during stimulus exposure, post-stimulus and pre-response, during response, and two post-response intervals) were selected and the maximum amplitude of the action potential during each interval was read as an indicator. Those six measures were combined, according to a technique described in Chapter XX of this report, into a single indicator. Data from questions answered "yes" were analyzed separately from those occurring on questions answered "no". For questions answered with "yes" movements the combinative indicator was larger for lying as compared with non-lying responses in 18 out of the 19 cases, showing a correct classification of 90-95%. For questions answered with "no" movements, this dropped off to 13 out of 19 cases or to 65-70%.

CHAPTER IX

EXPLORATORY STUDIES IN THE DETECTION OF DECEPTION: HAND MOVEMENTS AS THE SOLE INDICATOR

As parlor magicians well know, individuals tend to make small movements toward a hidden object when asked about the spatial location of the object and a sensitive observer can by holding an individual's arm utilize these movement cues to find the object. Interrogation of the participants in this trick suggests that: (1) the magician uses small movements of the arm as cues for his detection and (2) the individual is unaware of his production of such cues or (3) if he is aware of the possibility of these movements, he cannot control them.

In the belief that small movements of this kind might be utilized for lie-detection, an experimental situation was set up in which the subject answered "yes" and "no" respectively by arm movements in opposite directions. Questions, some of which evoked lies, were asked of the subjects. A time interval was introduced between the presentation of the question and the subject's response to it, in the hope that small movements toward one side or the other during the waiting period would betray deception. Some subjects were blindfolded and others not since awareness of the movements might depend on visual cues.

No evidence of discriminative power was found in the data on movements that were obtained.

CHAPTER X

AN INVESTIGATION OF EYE-MOVEMENTS IN DECEPTION

It is a fairly prevalent belief that liars are "shifty-eyed" and "will not look you in the eye." The purpose of this investigation is to determine whether lying produces characteristic patterns of eye-movements which can be used as indicators of deception.

Procedure

Fifty-two male and female undergraduates were used as subjects. Before coming to the experiment, they were assigned at random to one of the groups described below.

Upon reporting for the experimental session, each subject was shown a closed black box, 6 inches square. He was instructed that, after E left the room, he was to open the box, carefully observe the interior, to read any instructions inside. A diagram of the interior of the box is shown in Fig. 1.

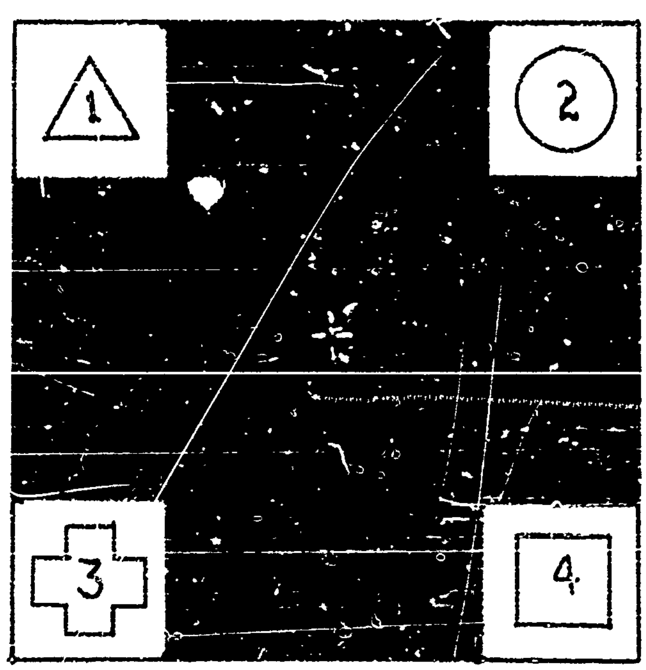

Fig. 1

Group ML (Motivated Lie)

For Group ML, the following typewritten instructions were placed in the box:

"Please read these instructions carefully and be sure that you remember what you are to do.

"You will notice that there is a coin in the box. You may take the coin. Please notice where in the box the coin came from. When you are questioned, you are to lie on all questions concerning the coin. If you deceive the experimenter you may keep the coin. Now call the experimenter into the room.

"Be sure you have read these instructions carefully and understand them.

"PLEASE REPLACE INSTRUCTIONS IN BLACK BOX."

Group UL (Unmotivated Lie)

"Please read these instructions carefully and be sure that you remember what you are to do.

"You will notice that there is a coin in the box. You may take the coin. Please notice where in the box the coin came from. When you are questioned, you are to lie on all questions concerning the coin. Now call the experimenter into the room.

"Be sure you have read these instructions carefully and understand them.

"PLEASE REPLACE INSTRUCTIONS IN BLACK BOX."

Group MH (Motivated Honest)

"Please read these instructions carefully and be sure that you remember what you are to do.

"You will notice that there is a coin in the box. You may take the coin. Please notice where in the box the coin came from. You are going to be questioned about the coin. If you answer these questions truthfully, you may keep the coin. Remember, to keep the coin, you must be absolutely honest. Now call the experimenter back into the room.

"PLEASE REPLACE INSTRUCTIONS IN BLACK BOX."

Group UH (Unmotivated Honest)

"Please read these instructions carefully and be sure that you remember what you are to do.

"You will notice that there is a coin in the box. You may take the coin. Please notice where in the box the coin came from. When you are questioned, please tell the truth to any questions concerning the coin. Now call the experimenter into the room.

"PLEASE REPLACE INSTRUCTIONS IN BLACK BOX."

Group NC (No Coin - Control)

"Your instructions are simply to call the experimenter back into the room.

"PLEASE REPLACE INSTRUCTIONS IN BLACK BOX."

For subjects in Groups ML, UL, MH, and UH, a 50-cent coin had been placed in one of the quadrants of the black box. As the instructions indicate, the subject was asked to take the coin. For Group NC, no coin was used.

After completing one of the above procedures, the subject was called into another room, was seated, and his head was positioned in the head-rest of an ophthalmograph (American Optical Company); the ophthalmograph was modified so that horizontal eye-movements were obtained from the subject's right eye, vertical movements from his left eye. These eye-movements were recorded photographically on 35 mm. film by means of the corneal reflection method.

After focussing the subject in, the film motor was started and eye-movements photographed for a period of 10 seconds. At this time, there was inserted into the card holder of the ophthalmograph a diagram drawn to duplicate the interior of the black box from which the coin was taken. Eye-movements for another period of ten seconds were photographed.

Next, the subject was instructed to look at each quadrant, beginning with quadrant 1. Photographic records of these movements were made. This gave a measure of magnitude of eye-movements for each subject, and later magnitudes were compared against these.

Next, the following questions were asked, at intervals of 10 seconds:

1. Is your name John (or Joan)?
2. Did you take a half dollar from the black box?
3. Do you like baseball?
4. Did you take a half dollar from the section of the box numbered ____?[1]
5. Were you born in the state of Kentucky?
6. Did you take a half dollar from the section of the box numbered ____?
7. Do you like lemon meringue pie?
8. Did you take a half dollar from the section of the box numbered ____?
9. Do you wear glasses?
10. Did you take a half dollar from the section of the box numbered ____?

For subjects in Groups ML, MH, UL, and UH all of the above questions were asked. For subjects in Group NC, only Questions 1, 3, 5, 7, 9 were used. During this time, eye-movements were being recorded continuously.

Results

1. What is the effect of presenting the card containing a diagram of the interior of the black box?

Movements during the 10 second period before presentation of the card were compared with movements during the 10 second period after the card. The results of this Before Card - After Card analysis are shown in Table I. In all groups, there was an increased tendency to look toward the guilty quadrant.[2] This increase occurred whether subjects were instructed to lie or be truthful, whether motivated or unmotivated. The size of this increase, however, was greater for liars than for truthful subjects.

[1] For Question 4, the number of the guilty quadrant was used.

[2] Guilty quadrant is defined as the quadrant from which S took the coin.

	HONEST		LIARS	
MOTIVATED	Before	.18	Before	.33
	After	.22	After	.47
UNMOTIVATED	Before	.11	Before	.12
	After	.16	After	.32

TABLE I

Before Card - After Card Comparison

This table shows relative frequency of movement to guilty quadrant, for each group of subjects, before and after presentation of card containing diagram of interior of black box.

2. Does a loaded question elicit a different pattern of eye-movements from those elicited by innocent questions?

For this analysis, relative frequencies of eye-movements to guilty quadrant for Question 2 compared with the Pooled Innocent questions (Questions 1, 3, 5, 7, and 9) were computed. Table II shows that Group ML (motivated liars) looked at the guilty quadrant relatively more for Question 2, whereas Group UH (unmotivated honest) looked at the guilty quadrant relatively less.[3] Table II is presented as a 2 x 2 table with "Dishonesty" as one variable and "Degree of Motivation" the other variable. An interaction between these two variables is apparent from inspection.

	HONEST	LIARS
MOTIVATED	5 greater 3 less 2 same	7 greater 3 less 1 same
UNMOTIVATED	2 greater 7 less 2 same	3 greater 3 less 3 same

TABLE II

Question 2 Movements Compared with Movements to Pooled Innocent Questions

Table shows number of subjects showing greater movement to guilty quadrant for Question 2.

[3] In this preliminary report, results are presented only in a tabulated form, similar to the above. The statistical significance of these results has not been determined by statistical analysis.

3. <u>Is the extent of eye-movement elicited by loaded questions greater than that elicited by innocent questions?</u>

In order to measure size or extent of an eye-movement, the film record was projected on a standard grid screen. The measure of extent used here is the ratio of the magnitude of a movement to the magnitude of the previously obtained instructed movement in the same quadrant.[4] This measure was only made for the first movement in response to each question.

Table III shows these magnitudes for Question 2 and for the Pooled Innocent questions. Motivated subjects show a greater-sized movement to Question 2 than to Pooled Innocent questions. For Unmotivated subjects, the direction of this difference was reversed.

	HONEST		LIARS	
MOTIVATED	Question 2	1.68	Question 2	1.20
	Pooled Innocent	1.18	Pooled Innocent	1.09
UNMOTIVATED	Question 2	.98	Question 2	.84
	Pooled Innocent	1.49	Pooled Innocent	1.31

TABLE III

Extent of Movement to Question 2 Compared with

Extent to Pooled Innocent Questions

4. <u>Do eye-movements of "guilty" subjects differ from those of control subjects?</u>

The results for Question 2 were analyzed to determine how many subjects in each group exceeded the control group in relative frequency of eye-movement to the guilty quadrant. The results, in Table IV, show that motivated liars moved their eyes to the guilty quadrant more frequently than the control group; unmotivated honest subjects showed this movement less frequently.

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4 Inasmuch as the movement had been previously broken into horizontal and vertical components by means of optical apparatus, it was necessary to recombine the two into one magnitude. This was computed as the hypotenuse of a right triangle whose horizontal and vertical sides are known.

	HONEST	LIARS
MOTIVATED	5 greater	7 greater
	5 less	4 less
UNMOTIVATED	2 greater	3 greater
	9 less	6 less

TABLE IV

Comparison of experimental groups with control group. Table shows, for Question 2, number of subjects moving eyes to guilty quadrant, with greater frequency, and with less frequency, than in control group.

5. Do "guilty" subjects show differences in eye-movements from control subjects, even for innocent questions?

Was there a tendency for guilty subjects to move their eyes toward the guilty quadrant, even on the innocent questions? Relative frequency of movements toward guilty quadrant for these subjects was compared with corresponding figures for control group.

The experimental groups showed a tendency to make fewer eye-movements, on the innocent questions, than did the control group. These results are shown in Table V.

	HONEST	LIARS
MOTIVATED	2 greater	4 greater
	7 less	7 less
	1 same	
UNMOTIVATED	5 greater	2 greater
	5 less	6 less
	1 same	1 same

TABLE V

Relative frequency of eye-movements to guilty quadrant for innocent questions, each group compared with control group. For example, in Group ML, four subjects exceeded the control group, seven subjects were lower.

While this result seems contrary to expectations, it might be explained by assuming that the subjects in the experimental groups tend to avoid the guilty quadrant, that this avoidance tendency is overridden by opposing tendencies for loaded questions, but that, on innocent questions, this avoidance tendency operates to lower frequency of movements to the guilty quadrant.

Summary of Results

1. Presentation of diagram of interior of black box caused more eye-movements to guilty quadrant for all groups of subjects. The size of this increase was greater for liars than for truthful subjects.

2. A loaded question (such as Question 2) caused more frequent eye-movements to guilty quadrant for Motivated Liars, fewer movements to guilty quadrant for Unmotivated Honest.

3. A loaded question (such as Question 2) elicited eye-movements of greater magnitude for Motivated subjects, movements of lesser magnitude for Unmotivated subjects.

4. Subjects in the experimental groups (especially ML, MH, and UL) made relatively fewer eye-movements to guilty quadrant, for innocent questions, than did the control group.

PART II

MAJOR MULTIPLE-VARIABLE EXPERIMENTS

CHAPTER XI

RESPONSES OF THE CIRCULATORY SYSTEM: THE BASIC VARIABLES AND THEIR RELATIONS

The responses of the circulatory system are thought to be of great importance, in both theory and practice, (Mowrer (14) for example assigns them a principal role in his theory of anxiety, and in the usual lie-detection technique blood pressure is one of the major variables, and heart rate apparently a subsidiary one). There are a great many interrelated events in the circulatory system, many of which could be recorded and used as indices of response. To know what sequence of events may be set off by stimulation and to choose from these events the ones which are best to record (give the most information with the greatest convenience), it is advantageous to consider the dynamics of the response system and then to check deductions from this knowledge with data. On some points, however, available physiological knowledge leads to no expectations, and it may be necessary to proceed altogether empirically.

The interest of physiology and biophysics has been chiefly in the regulatory mechanisms of the circulatory system. Their problem has been to understand how a state of equilibrium is maintained in the system or how the system adjusts to a disturbance once the disturbance has been produced. For psychology the interest is somewhat different: it needs to deal with responses initiated by events outside the organism. The adjustment of the system to disturbances within itself will then be sequelae, responses to responses. For psychological purposes therefore it is necessary to consider the cardio-vascular complex as a response system, with an input, an output and a number of internal couplings which affect the relation between these two.

What is considered as the output of the system will depend on the particular purposes of the investigator. In case he is studying the effects of circulatory state upon behavior he would do best to locate the points of coupling between the circulatory system and the neuromuscular system which executes the behavior in question, and measure the circulatory output delivered at this point. Very likely this output will not always correspond to the biologically essential output of chemical substances from the system. One of the known coupling points however would be the output of these substances to muscle and nerve, for muscular operation would be affected by their supply. (Darrow (3) has discussed this mechanism for the brain.) Visceral-skeletal reflexes (Gellhorn, 4) would be another coupling mechanism. The investigator, however, is at present handicapped by lack of information on these couplings, and their relative importance.

One may on the other hand be interested in the reverse problem, that of discovering the antecedents of the circulatory event. Such is the case in lie detection, for the experimenter wishes to find whether the subject has lied or at least was intending to lie. He is not particularly concerned with the effects of the visceral response upon the future actions of the individual. His guiding principle would be to select as "output" some variable which most closely reflects the input. On general grounds one would expect this to be found as near as possible in the chain of events to the input where there would be least opportunity for it to be transformed or to be corrupted by intervening events.

So the investigator needs to look for the basic variables in the circulatory system, and the origins of their variation, to decide which will best reflect inputs to the system coming from the external receptors, and to devise means for recording the chosen variable as accurately and conveniently as possible.

In circulatory adjustments humoral influences of course play an important role in the long run. But if one is interested in the effects which occur in a few seconds following a stimulus it seems proper to simplify the problem by neglecting these relatively long term effects. In the following analysis, therefore, little attention is paid to the hormonal and other humoral effects.

The fundamental structure of the system is a closed hydraulic loop containing a force pump.* (This loop consists of course of two sub-loops, the pulmonary and peripheral, forming a figure eight as it were, with one half of the heart in each part.) Flow from the heart is maintained by the force of its beat; but the pressure gradient it produces declines almost to zero in the capillaries and extra systemic forces are necessary to return the blood (Ponder, 15; Green, 5). These are provided in important measure by the compressive action of skeletal muscle contraction and by the negative pressure in the chest cavity which results from respiratory movements. As in hydraulic systems in general there are three physical variables, pressure, flow, and resistance which describe its operation in a steady state. These are related to each other in the same manner as their electrical analogies, e.m.f., current, and resistance are related by Ohm's law. For a steady state, therefore, any two of the variables would specify the over-all state of the system.

But of course the system is not in a steady state: the pulsations introduced by the heart and the aperiodic responses in which the psychologist is interested continually introduce changes into it. Because of the elasticity of the vessel walls the system is physically reactive to the change, as an electrical circuit containing inductance is reactive. The disturbance will take some time to produce a new steady state, and there will be a definite transmission time from one part of the system to another (King, 12). Thus in the average young adult it takes about one third of a second for a disturbance to travel from the heart to the finger tip (see section on pulse velocity in this report). This hydraulic conduction is, of course, much slower than most nerve conduction, yet much faster than the transport of blood. It will proceed in both directions from the origin of the disturbance except at the heart where the valves prevent any substantial backward transmission.

Forward transmission through the heart is, however, of the greatest importance. It takes place because the force of the beat is principally determined, without neural intervention, by the distension of the ventricles which itself depends upon the local venous pressure, according to Starling's "law of the heart" (Hoff, 11). This pressure, in turn, is affected by anything that happens anywhere in the system. Transmission of an effect across the heart entails further delay, since the heart beat cannot even begin to change in force until the next systolic contraction. On the average this delay would amount to about half a heart cycle: about a third of a second.

* For the basic physiological facts reliance is placed on (2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16). The interpretations, however, are the responsibility of the writer.

Within the circulatory system there are a number of regulatory mechanisms which operate as feed-backs. Certain of these, operating in a negative direction tend to maintain homeostasis; others, with respect to certain variables at least, operate in a positive fashion and tend to exaggerate any disturbance (Barron, 2). Some of the feed-backs operate altogether by hydraulic transmission; others are neural reflexes. The simplest feed-back mechanism perhaps is the elasticity of the vascular walls. An increase in pressure, produced say by a stronger heart beat will stretch these walls, enlarging the volume of the system, thereby reducing the pressure within it in some degree. This would take about a third of a second, as stated above. The distention would also keep some blood from returning to the heart, there being more room for it in the vessels. The ventricle would not fill so rapidly and the next systole would be weaker because the ventricle would be less distended. If the disturbing force were by now removed this would be sufficient to reduce the arterial pressure and permit the peripheral vessels once more to resume their normal size, returning the system to its original state all round. A temporary modification of the peripheral resistance variable will have brought all variables back to their original state.

But should the disturbing force be continuous, no temporary adjustment of peripheral resistance or anything else in the system can bring back the original state of all variables. If a pressure is continuously applied to the system something must be adjusted to oppose it. Energy delivered to a system cannot simply vanish. If internal pressure is to be constant the peripheral resistance must remain lowered, the rate of flow increased, or both. Empirical evidence needs to be examined to see whether all three variables are modified under these conditions, reaching a new state of equilibrium, possibly through a series of oscillations depending on the damping constant of the system.

The elasticity of the vessel walls has another result which operates to exaggerate a disturbance. Should they become more dilated in one region than in another increased blood pressure will stretch still further those already dilated (Green, 5) leading sometimes to serious consequences.

An important neural regulator is the reflex whose receptors are located in the aortic arch and carotid sinus (Heymans, 10). These receptors are stimulated by pressure in the arteries and are normally in a state of activity. These excitations are carried to the vasodepressor center by the vagus and glossopharyngeal nerves. Efferent impulses (parasympathetic) are then returned to the heart, slowing its rate, and to the walls of the vessels, causing them to dilate. Both these changes would lower the pressure and make the reflex a negative feed-back with a stabilizing effect on pressure.

A similar pressure reflex operates from receptors in the large veins near the heart over a vagus afferent and a sympathetic efferent. When venous pressure rises this reflex produces cardiac acceleration (Bainbridge reflex) and possibly vasoconstriction (MacDowall reflex) (Barron, 2). These reflexes therefore operate as feed-backs with a positive sign, increased venous pressure leading to events which produce a further increase in venous pressure. The relations of this to the aortic arch reflexes seem not well understood. On the one hand the aortic arch reflexes seem to be dominant -- in the long run they or their equivalent must be, or there would be no stopping. On the other hand there are (during some kinds of stimulation for example) occasions when heart rate and vasoconstriction are maintained at an elevated level.

In the regulation of mean blood pressure, variations in heart rate seem to be of much less importance than variations in peripheral resistance. Over the normal range of heart frequencies the minute output of the heart varies but little with frequency (venous pressure being constant). The volume ejected by the heart at each stroke will vary enough to compensate for the rate change because of the variation in time available for filling of the ventricles (Barron, 2). Hence it is usual that heart rate is driven by blood pressure in negative fashion through the depressor reflexes, rather than vice-versa. (Marey's law) (Hoff, 11). The case of pulse pressure is somewhat different. Inasmuch as a faster heart rate will allow less ventricular filling the stroke volume of the heart will be reduced, although the minute volume remains about constant. The size of the pressure pulse therefore would be reduced, other things being equal, when the heart rate is increased.

Only a rough estimate is possible for the time taken for the autonomic feed-backs to operate. Latencies for autonomic responses externally initiated seem to be of the order of a second or more. In an autonomic-autonomic reflex one might guess the time would be twice as great, amounting to several seconds. Certain published records (on dogs) show values in the neighborhood of 5" (Hoff, 11). After the cessation of a disturbing factor the original equilibrium is apparently not restored for upward of a minute (Weiss and Baker, 17).

The most important "input" to the circulatory system, from the standpoint of the body's economy, is the effect of local muscular activity. The metabolites of contracting muscle will produce a local vasodilation. As this is probably a relatively slow process, however, its direct influence may be ignored for the present purposes. Aside from this, and other humoral effects, the "inputs" to the circulatory system are both neural and mechanical. The most direct effects of outside stimuli are evidently impressed upon the system neurally. This coupling with the external world occurs at two locations in the system: the heart and the vascular walls. The "reservoirs" of blood such as the splanchnic are sometimes spoken of as though they constituted yet another locus of input. Since they consist of vascular networks, there would seem to be no need to set them apart, unless it is shown that they have some special status aside from the rest of the vasculature. At each of these sites the effect may be in either positive or negative direction, and either effect may be produced by direct or inverse acting nerve fibers (for the heart, pressor and depressor, for the vessels, constrictor and dilator). An increase in the action of one of these will be equivalent in sign to a decrease in the action of the other. For the heart the direct acting nerves (pressor) fibers are sympathetic, the inverse acting ones, parasympathetic. For the vessel walls the direct acting fibers (constrictor) are sympathetic, the inverse (dilator) fibers, on the other hand, are parasympathetic, sympathetic, by origin at least, and somatic (Barron, 2). These latter conduct the curious antidromic axone reflexes which would produce vasodilation primarily at the site of stimulation.

With two mechanisms operating reciprocally and having a reciprocal central connection (2) it would seem to be immaterial which one is said to produce a given effect. The other would always be contributing by a change of opposite sign. There are however two ways in which it does make a difference. Where one of the mechanisms is sympathetic and the other parasympathetic we should find, according to the usual belief, that the sympathetic would affect a larger segment of the organism. Possibly we should expect to find reciprocal action at only one site; at others a variation in sympathetic action without much change in the parasympathetic. This implication, of course, needs verification by observation. In the second place the external receptors for the two systems and the pathways leading to the autonomic centers are probably independent, and not reciprocally related. Hence it is possible that both should be activated or deactivated at once. With a central reciprocal connection having less than perfect transmission this would mean that both systems would deliver increased discharge to the elements of the circulatory system which they control. This would provide opportunity for the pressors and depressors to vary consensually as well as reciprocally and would be the origin of the state of general autonomic excitement postulated by Arnold (1). So it is necessary to regard the contribution of both direct and inverse operating systems, since the action of one cannot simply be inferred from the action of the other.

It is thought that for the heart the parasympathetic circuits are the more important (Hoff, 11). Adrenalin administered in small doses generally brings about a slowing of heart rate. This seems to mean that it first raises the blood pressure by vasoconstriction, and that this pressure excites the parasympathetic reflexes sufficiently to offset any direct pressor effect it may have on the heart. Presumably a discharge over the pressor fibers would be similarly outweighed. On the other hand the experiment seems to suggest that peripherally the sympathetic has relatively more effect.

The neural pathways from external sense organs to the cardiovascular system are quite numerous. The simplest, of course, is the already mentioned axone reflex in which afferent nerves conduct in both directions to produce vasodilation. More complex routes for both direct and inverse acting systems probably lie through the spinal cord, through the medulla, and superimposed on these through the mid-brain and through the cerebral hemispheres. For the vasoconstrictor effects, it is said that stimulation of any of the afferent nerves (except those involved in the carotid sinus-aortic arch reflexes) will produce them without necessarily having any direct effect on the heart (Barron, 2). The action of the sympathetic in constricting peripheral vessels is usually thought to be spread through the whole organism. Its effects, however, are not the same in all regions. The vasculature of the brain, though innervated by the sympathetic, is little subject to the vasoconstrictor reaction (Schmidt, 16). Consequently a general vasoconstriction will have the general effect of increasing the blood flow through the brain. In muscular and glandular regions the vasoconstriction is also differential because the local dilation (produced by the metabolites of local activities) is prepotent over the vasoconstriction (Heymans, 10). Constriction in the less active parts, therefore, will force more blood into those active parts. Vasodilation is reported to be produced by the stimulation of certain local regions, parts of the sex organs for example. Presumably the pathways for any of these, as for pressor and depressor effects on the heart, would be through the autonomic centers by means of side branches from ascending tracts or by a return from the cerebral hemispheres through the autonomic centers.

Besides the direct neural inputs to the circulatory system there are a number of mechanical inputs. A response (to neural discharge say) taking place in some other organ system may impinge upon the vascular system. Especially important action of this sort comes from the skeletal muscles and from the respiratory system. Muscular activity has the local effect of dilating the blood vessels, so that in exercise there is a copious blood supply. This would probably take a little time to develop, but the antidromic reflex might come into operation and produce vasodilation rather quickly. Since in the human the pressure exerted upon the capillaries and venous system plays an important role in forcing the blood to return to the heart, a variation in this pressure would modify venous pressure and flow. Because of the short latency of skeletal muscle responses this route would produce the earliest modifications in the vascular system, increasing the venous pressure in a few tenths of a second.

The respiratory system also makes a mechanical contribution to the circulation. The negative pressure in the thoracic cavity assists the return of the blood to the heart. This negative pressure becomes still greater during inspiration. The effect is again to increase venous pressure at the entrance to the heart, and of course start the train of sequelae therefrom. A decrease in the size of an inspiration for example would lead first to a fall in blood pressure. The time involved would be rather long, because of the slowness of the breathing cycle.

With the system receiving inputs from these various sources, and with internal feed-backs operating as already described one may try to discern what sequences of circulatory events would follow. Various cases must be considered.

1. The simplest cases would be the hypothetical one in which external stimulation excites the sympathetic centers and not the parasympathetic (except through reciprocal action). Neglecting for the moment a possible somatic muscle tension effect, sympathetic impulses would reach the two major input points of the circulatory system, the heart and the peripheral vessels. Because of the shorter route it might be expected to reach the heart first, perhaps in less than a second. Two effects would thereupon appe[illegible]: the rate of the heart would increase, and the stroke volume decline. Be[illegible]se of this decline the pulse pressure would also fall, with the mean [illegible]ure remaining about the same. When the sympathetic impulses reached [illegible] peripheral vessels there would be a vasoconstriction. This would produce an increase in venous pressure, which after some delay would reach the region of the heart. There the pressor reflexes, leading to further cardiac acceleration and possibly vasoconstriction would be set off. Because of their latency, these effects would not appear for a time. There would, however, be an [illegible]mediate effect of more rapid ventricular filling and increased stroke volume which would increase both the pulse pressure and the mean arterial pressure. The aortic arch-carotid sinus reflexes would be set off and in time exert a braking effect by reducing the heart rate and vasoconstriction.

2. Since sympathetic routes from periphery are so common it seems likely they would always be involved in some measure in a response to a stimulus unless possibly they are already in maximum action. The parasympathetic, however, can probably be aroused in greater or lesser measure along with the sympathetic. A general parasympathetic action would oppose the sympathetic effects at both heart and periphery. If the heart is more susceptible to parasympathetic effects, a weak arousal of that division would, superimposed on the sympathetic, give the same picture as that described for the first case, except for a cardiac slowing instead of acceleration. If the parasympathetic, or more exactly dilator-depressor effects were dominant everywhere the whole sequence would be inverted. Since it seems characteristic of the parasympathetic to act independently in different regions, all sorts of mixtures of effects could be produced

depending on local dominance. A systemic variable like blood pressure, of course, would reflect the net balance between the two effects on a system-wide basis.

With this analysis in mind one can examine recorded cardiovascular responses to see whether they accord with the expected patterns, and which one will appear in particular situations and particular individuals.

Fig. 1 presents a common type of record of the changes in pressure pulse and volume pulse to a strong noise stimulus. The pressure pulse was recorded from a crystal pick up with a small button attached to its point, the whole being strapped over the radial artery at the wrist. The volume pulse was taken from a finger tip (on the opposite hand, it so happened) by means of an impedance plethysmograph. (The details of these instruments are given in the following chapter.) Although relations can be seen in the one record, the mean responses of a group of subjects will show them with fewer variations. In one group, therefore, eight S's were given noise stimuli (loud tone, about 1" duration) after they had finished a sitting in a lie-detection experiment. Two stimuli were given each S. The means are shown in Fig. 2, with the measurements made at each pulsation, and plotted as a function of pulses rather than of time. In another group of 12 S's similar measures were taken, the only difference in the situation being that the S's were given the auditory stimuli (four each at intervals of a minute as soon as they were connected to the apparatus). Their responses are shown in Fig. 3.

It is clear in Fig. 1 that there are inverse responses in the pressure and volume pulses. The volume pulse undergoes a marked decline and actually disappears as far as this record is concerned. At about the time the volume pulse reaches a minimum the pressure pulse shows a marked increase. In other words the pressure pulse acts reciprocally after about 5" delay. Such action is also to be seen in Fig. 2. At first glance the two lines in Fig. 2 (volume and pressure amplitude) seem roughly parallel, but it should be noted that after the 11th post-stimulus cycle the pressure pulse is above rest level, while the volume pulse is still below it. In Fig. 2 and Fig. 3 there is clear evidence of a diphasic response in both the pressure pulse and the pulse interval (inverse of heart rate). At the same times in both groups, there is an acceleration-depression pattern then a deceleration-enhancement pattern.

In Fig. 3 there is an "anomalous" response in the volume pulse. At the time it decreases in the previous records it now increases by a similar amount.

The latency of initial responses in all three variables seems to be 2-3 heart cycles, possibly one cycle shorter for the heart rate response than for the constriction of the volume pulse. This makes the latency about the same as that for the g.s.r., another response autonomically mediated.

At least a partial interpretation of these results can be made on the basis of the foregoing analysis. In Fig. 1 and Fig. 2 there is evidently a sympathetic reflex action which accelerates the heart and constricts the vascular bed. The changes in the pressure pulse ought to be referable to changes in the other two variables. There are two reasons, therefore, why the pressure pulse should fall during the first phase of the response in Fig. 2. (There is some indication of its decline in Fig. 1 also.) An increased constriction of the peripheral vessels will raise the diastolic

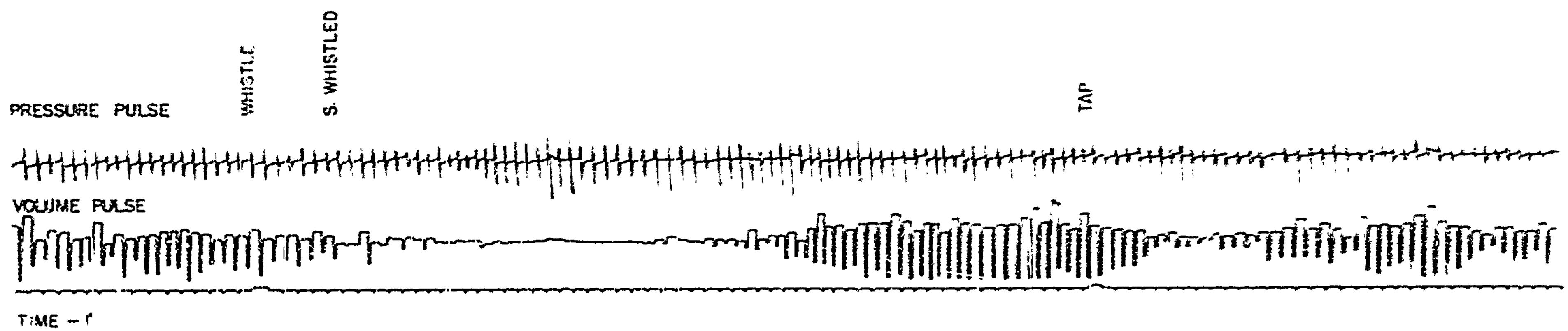

FIG. 1 PRESSURE AND VOLUME PULSE CHANGES (ONE SUBJECT)

TIME UNIT = 1"

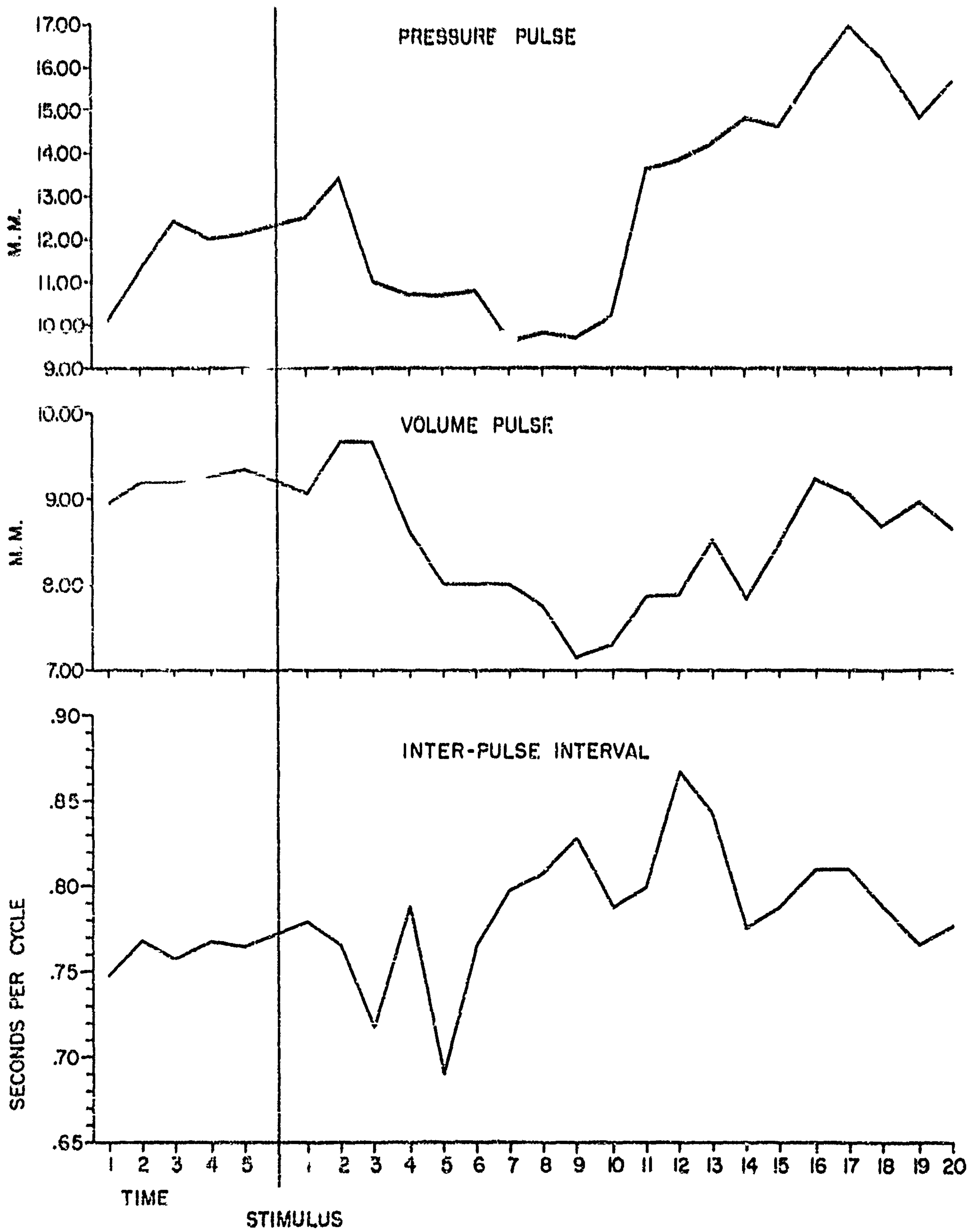

FIG. 2 PULSE CHANGES FOLLOWING BRIEF NOISE STIMULUS
MEAN VALUES FOR GROUP
TIME IN CARDIAC CYCLES

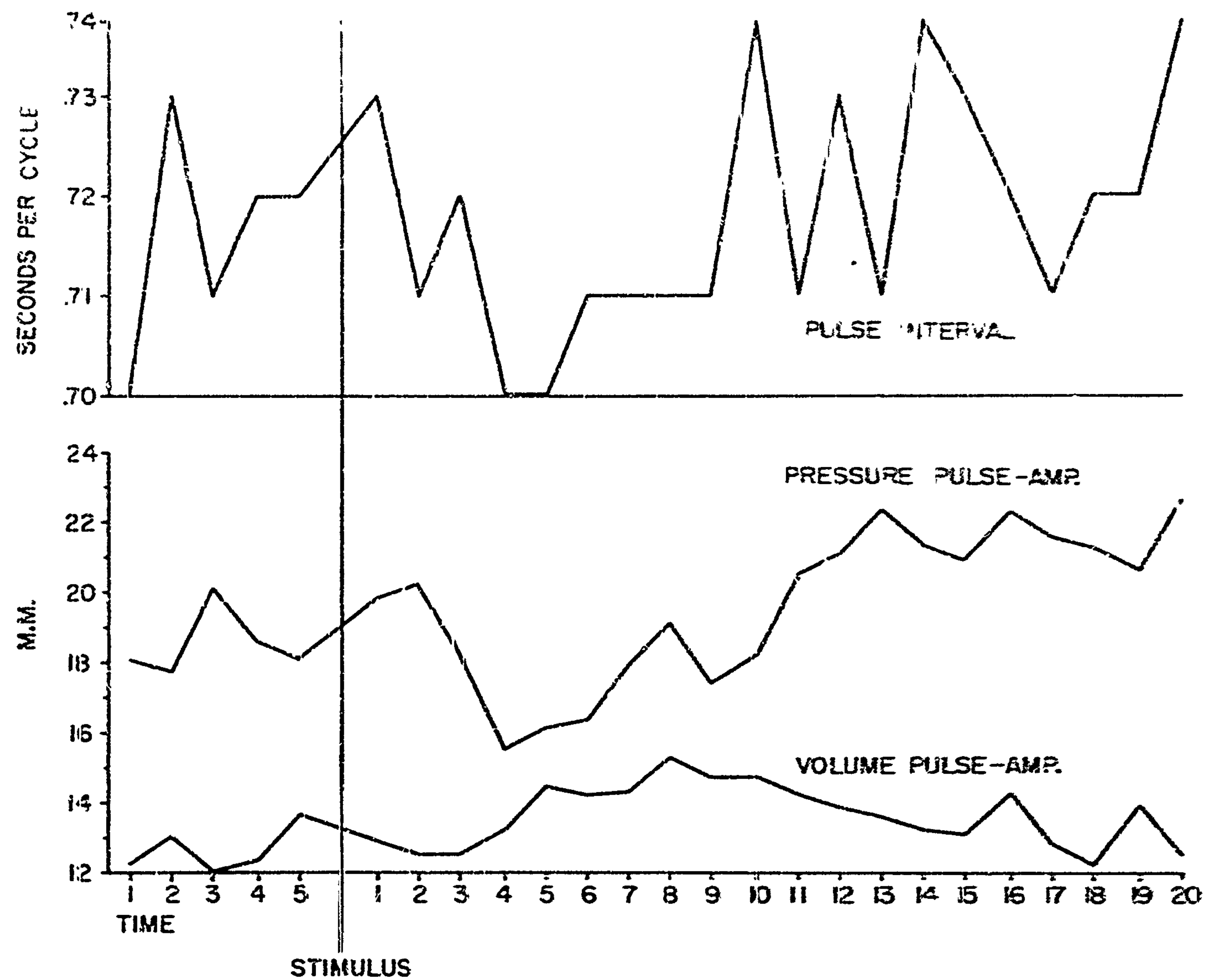

FIG. 3 PULSE CHANGES FOLLOWING BRIEF NOISE STIMULUS.
MEAN OF GROUP.
TIME IN CARDIAC CYCLES

pressure in the arteries, thereby making the pressure pulse smaller. Likewise acceleration of the heart, with no increase in its input makes a smaller stroke volume and therefore smaller pressure pulse. The decline in pressure pulse in Fig. 3 in the early part of the response must be referred to the heart effect alone, or to vasoconstriction in places not represented in the record.

The recovery of the heart from its acceleration, and in Fig. 1 and 2. the gradual reduction of vasoconstriction, would come about simply through cessation of the sympathetic discharge. The process might be assisted by the aortic arch and carotid sinus reflexes, though it seems doubtful that arterial pressure has been raised enough prior to this to affect them.

The second phase of the response, with slow heart rate and high pressure pulse could be expected as a consequence of the initial vasoconstriction. On account of the low pressure in the veins a change in pressure would take a long time to travel to the heart, and in order to raise pressure in the vena cava there would need to be some transport of blood, which would consume more time. Because of the vasoconstriction the ventricles of the heart will fill at a faster rate, but only after the transmission time, which might well amount to the 5" shown in the record as the time between vasoconstriction and pressure pulse increase. With faster ventricular filling the stroke volume of the heart and the pulse pressure (and mean pressure) would, of course, increase. With increased pressure the parasympathetic reflexes would act to slow the heart below its "normal" rate.

In the case of Fig. 3 it may be supposed that the same mechanism operates: that there is a vasoconstriction in some part of the body playing the same role as before, but that it is not so general as in the first case and does not include the finger. The physiological and situational conditions which determine this difference remain to be explored.

In brief we have, it seems, at least in Fig. 1 and Fig. 2 a diphasic cardio-vascular response which for convenience may be called Type 1. There is first cardiac acceleration and vasoconstriction; when the effect of vasoconstriction reaches the heart it produces the second phase of the response, an increased systolic and pulse pressure and consequently a below normal heart rate.

The average response to verbal stimuli in a lie-detection experiment was of this Type 1. (The experiment, described elsewhere in this report, used 59 S's who were questioned about "crimes" that they did and did not commit, subjected to threats of shock, and given neutral questions.) To all the varieties of stimuli the mean response was vasoconstriction. So far as the coarser time scale permits the heart rate and pressure reactions are seen also to follow the pattern of Type 1. (See results elsewhere in report.) The depressed phase [illegible] the pressure pulse could not possibly show since no measure was available at the proper time. There is generally an indication of an initial heart acceleration in this experiment, though with the heart intervals read in blocks of five as they were here it does not show as clearly.

These results confirm the suggestion of Arnold (1) that a stimulus may initiate a sequence of autonomic patterns, but the sequence here displayed differs from the ones she describes and seems to derive from a different mechanism from the one she had in mind.

Where it is desirable to secure an index of autonomic action, or to discriminate antecedent conditions in general, as one does in a lie-detection situation the preferred variables seem to be the heart rate and peripheral vasoconstriction. Since it is these which are first affected by the autonomic action there would be less opportunity for "contamination" by extraneous variables. Fortunately these two variables are also quite easy to record (see following section).

There is however the reservation about vasoconstriction, that it is very probably not always a general bodily response. (Fig. 3 seems to be a case where it is not.) To assess the overall vasoconstriction (or dilation) a pressure measurement is advisable, since the state of vasoconstriction, directly, and through the medium of venous pressure, is a principal determinant of arterial pressure. Whereas vasoconstriction is local, arterial pressure is a systemic parameter because the system is hydraulic. Among the arterial pressures systolic has been the traditional chosen measure. Diastolic pressure would seem, theoretically, to be just as promising. Pulse pressure, reflecting as it does the stroke volume of the heart, might turn out to be the most informative of all, particularly if it is considered in relation to the cardiac rate.

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CHAPTER XII

METHODS OF MEASURING CIRCULATORY VARIABLES

Since there are three basic cardiovascular variables, pressure, flow, and resistance, the experimental techniques used will fall into three general classes, each directed to the measurement of some variety of each of the three variables. There is the possibility of a fourth class: techniques which measure some combination of the three. Where such measurements consist of known components in known relations they may be very useful. Unsystematic and variable combinations should probably be avoided in scientific work, since they depend so much on the peculiarities of particular instruments.

Pressure measurements, in turn, are of two sorts. Some record the application of pressure by the heart to the rest of the system, others are concerned with pressures at various times and places within the vascular system. For the heart beat one may study the rate, force, and wave form of the cycle. In the present series of experiments there was no direct study of the force of the heart beat. Though this might be an interesting variable its study was not undertaken because of its dependence upon venous pressure (Starling's law), which in turn depends upon some of the other variables which were measured.

Heart Rate

The heart rate and regularity were obtained from several types of instrument. One, a modified form of electrocardiograph, was constructed especially for the purpose. This consisted simply of a rather high gain amplifier which fed into one channel of the common recording apparatus. For convenience in measuring records it seemed well to eliminate the smaller, slower components of the EKG and leave only the QRS complex. Therefore the amplifier was constructed to cut off the lower frequencies. The circuit is shown in Fig. 1. In using this system electrodes, consisting of 1/2" metal disks were strapped to the fore-arms over areas treated with electrode jelly (EKG Lead I). With the recording paper running at a speed of 1¼ in. per sec. it was possible to make measurements of the time between beats to about .01 sec.

This rather simple system is easy to operate and gives little trouble, the only adjustment required being that of setting the gain control, and one setting usually suffices for an S. Certain problems arise, however, when EKG recording is combined with other types of instruments attached to the S. (For this reason S is isolated from direct ground connection by means of a condenser.) The chief difficulties come from the combination of this instrument with the g.s.r. recorder. If there is any a.c. used in the supply circuits of the g.s.r. recorder or in its re-set motor (see g.s.r. apparatus) enough will be introduced into S to be picked up again by the EKG leads. Complete battery operation of the g.s.r. apparatus solved the problem of such a combination. It is, further, impossible to use a g.s.r. instrument attached to each of S's hands and record EKG at the same time. With two g.s.r. circuits attached to him S is grounded on both hands, and the arms, of course, become equipotential and yield no EKG. (The double grounding makes trouble for EKG recording from other electrode locations as well, though it may not be impossible, to find a satisfactory location.)

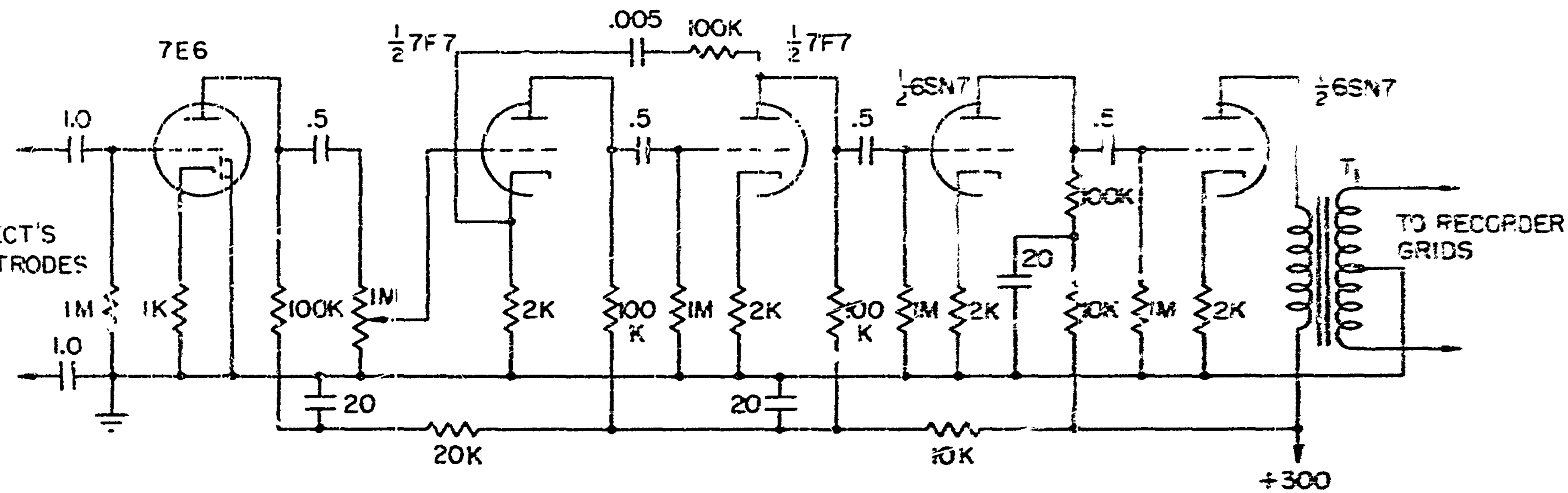


FIG. I E. K. G. AND PRESSURE-PULSE AMPLIFIER

In general, it seems to be more economical to secure the heart rate measure from one of the pulse recordings, for those give the heart rate as well as other information about the circulatory system. The EKG is necessary, obviously, for study of the heart-pulse interval (see below).

Arterial Pressure

The measurement of arterial pressures, systolic, diastolic and pulse pressure, the difference between the two, present serious technical difficulties. Basic research on the circulatory system requires that these be studied, and the previous results of blood pressure measurements in experiments on lie detection (Marston, 11; Chappell, 2) make it necessary for a methodological study of that application.

In his early work Marston took readings by hand with the usual clinical procedure. The limitations of the method are evident: readings cannot be secured very frequently or regularly, and they would require the full attention of an operator. To secure continuous records Larson (10) adopted the apparatus which Erlanger (4) had devised, but used it with less than enough pressure on the cuff to occlude the artery. The pressure variations in the cuff itself (produced by the pulse) are then recorded by a tambour. This is the technique in general use for lie detection at present. Chappell (2) pointed out its shortcomings more than twenty years ago. While the device does show changes related to blood pressure, they are related in a variable and unknown manner. It is often said it gives relative rather than absolute measures; it is probably more accurate to say that it gives non-quantitative records.

Several investigators have constructed and used rather elaborate devices for keeping the artery completely occluded automatically and recording the pressure that is necessary to do so (Lange, 9; Darrow, 3; Stokvis, 13) and at least one such device is on the market. The basic principle is to place a pulse detector of some sort below the pressure cuff and make it operate a negative feed-back into the pressure system. Technically these devices are quite satisfactory, but one hesitates to keep an artery occluded for an experimental sitting of any great length. Doing so is painful to S and might be harmful. Such instruments, of course, will record only systolic pressure.

A compromise plan of applying intermittent pressure to the artery was therefore adopted in the present experiments. Intermittent pressures had been used before (5); for our purposes however we needed a system which would apply pressure automatically in a determined fashion, and a pulse detector which would give a continuous record. The general plan was to apply pressure to a cuff so that the pressure on the artery would increase gradually in a linear fashion to some point beyond the occlusion point of the artery, to have the pressure then released and, after a brief pause applied again. Somewhere during the ascent of the pressure the pulse below the cuff would be cut off. Knowing when this happened from the continuous record it would be possible to read the corresponding point on the linearly ascending pressure curve, which would be the point of systolic pressure at the moment. A simple pump was constructed to apply pressure in this fashion. A reservoir of Hg was mounted on a lever arm (Fig. 2). This arm was raised and lowered by a motor driven cam so that the mercury well followed the pattern shown in Fig. 3. From the bottom of the well a tube (of glass, so far as possible)

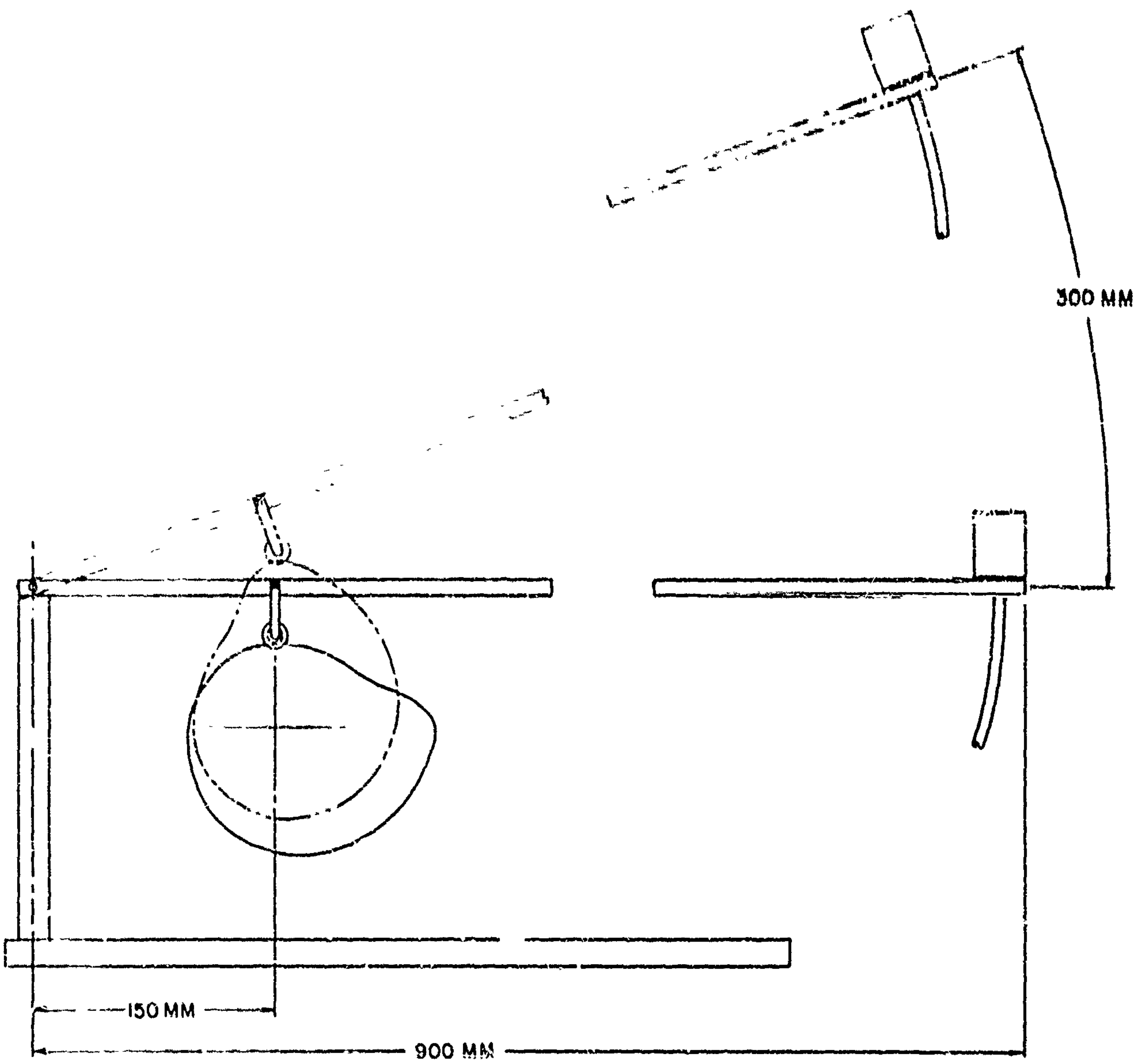


FIG 2 MERCURY PUMP FOR GENERATING OCCLUDING PRESSURE

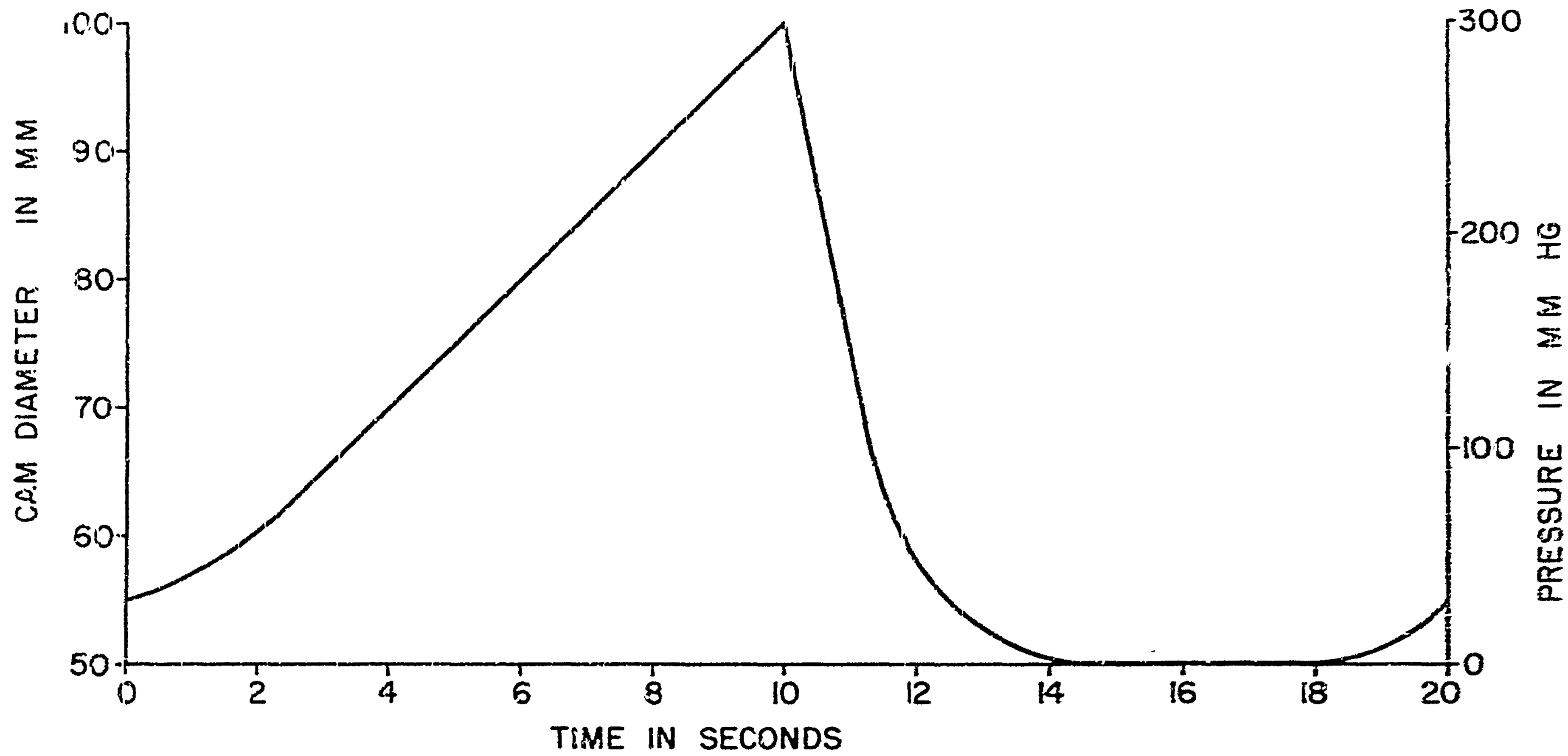


FIG. 3 CYCLE OF PRESSURE APPLIED BY MERCURY PUMP

led to the pressure cuff. Since it is desirable to keep the volume of the cuff as small as possible, it was made of a six inch length of surgical drainage tubing, 1/2" in diameter. (This tubing has very thin walls.) So far as possible this tube was kept from expanding in an outward direction from the arm by a tight bandage. When the cuff was applied it was drained of Hg, and of course was completely collapsed since air was removed from the system so far as it could be. As pressure was applied by the elevation of the mercury well sufficient Hg would enter the cuff to produce the required pressure.

As a pulse indicator in our earlier experiments we used the plethysmograph (see below) to record the volume pulse of the finger. In preliminary trials with S's in a resting condition this seemed to give credible values for the variations of blood pressure produced by drinking coffee, by age, etc. But the results of the early experiments in which S's were given stimuli showed the "blood pressure" behaving in an unlikely fashion. Reflection on the circulatory mechanisms revealed the reason. The stimuli were causing a vasoconstriction, probably rather general in distribution. This, and to some extent cardiac acceleration, was producing an increase in blood pressure which would tend to keep the pulse (below the cuff) beating a longer time in the face of the increasing pressure. The local vascular bed, however, was also undergoing vasoconstriction, and here the effect would be to obliterate the pulse sooner. The result was therefore a contest between the systemic vasoconstriction and the local. Whereas with no changes in vasoconstriction the technique would give a reasonable measure of blood pressure, it would not do so when the constriction changed. Unfortunately, of course this is the situation of interest in a psychological experiment.

It was necessary therefore to devise another means of indicating the presence of the pulse below the cuff. It was reasoned that the pulse in an artery is little affected by vasoconstriction. By strapping a crystal pick-up with a small button on it over the radial artery we were able to pick up its pulse. This was amplified with the EKG amplifier and put on the recording paper through one of the pens. The beginning of the application of pressure on each pump cycle was indicated by a brief interruption of the writing voltage of this pen.

By this device we have a parallel to the usual clinical situation of taking blood pressures by palpatory or auscultatory procedure. A typical record is shown in Fig. 4. In reading such records the diminishing peaks of pulse waves were connected with a straight line, and the point of its intersection with the base line taken to represent the systolic pressure. There is reason to believe that diastolic pressure can also be read. As the pressure climbs the pulse will, after a point, begin to increase (see Fig. 4). With still greater pressure it decreases and disappears. The increasing phase would evidently come about because blood flow into the artery is being more and more cut off during diastole, and when it is completely cut off the pulse pressure is working into a collapsed artery, producing a bigger variation in it. This point of maximum pulse, therefore, should represent the point at which diastolic pressure is just balanced out: that is, the diastolic pressure. This point has been measured in the experiment where this recording method was used.

If no pressure cuff is used the record from the crystal pick-up may be expected to indicate pulse pressure: i.e., the amount of swing the arterial pressure undergoes on each pulse beat. Even where there are periodic

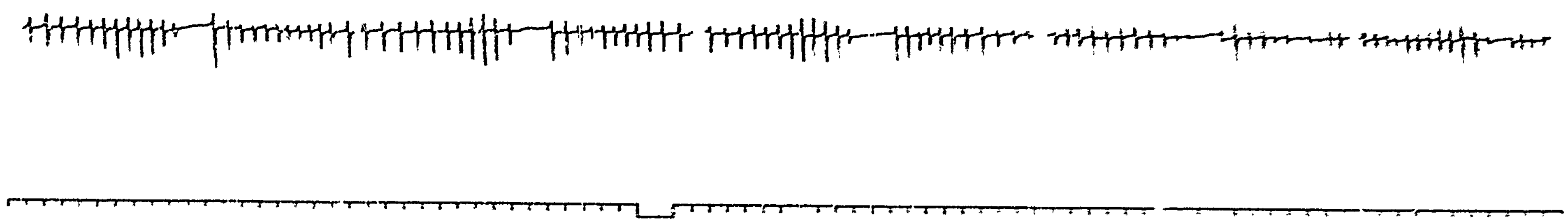


FIG. 4 ARTERIAL PRESSURE PULSE SHOWING OCCLUSION AT POINT OF SYSTOLIC PRESSURE, BREAKS IN LINE INDICATE BEGINNING OF PRESSURE APPLICATION.

applications of pressure from the cuff the size of the pulse wave may indicate this pulsatile pressure if measurements are made at corresponding points in the pump cycle. Such measures were also taken on the records.

As a whole this method of securing arterial pressures seems quite promising. Certain features, however, ought to be improved. It is rather cumbersome to establish the point of zero cuff pressure, since it depends on the relative height of the cuff and pump. This was measured crudely for each S, but no use was made of the measure in handling the data. Too much depends, also, on the skill of an operator in getting the wrapping tight around the pressure cuff. A loose wrapping will permit too much Hg to enter the cuff with the result that cuff pressure does not follow the movement of the pump arm. In the present experiment we are concerned with changes in arterial pressure as the stimulus is applied and more importantly with differences in these changes within an individual. These seem to be represented reasonably well, though we would hardly be able to give the total arterial pressure in absolute units.

Pressure and Resistance Measure, the Velocity of the Pulse Wave (Heart-Pulse Lag)

When the heart beat forces a quantity of blood into the aorta a shock wave is introduced into the fluid in the system. The blood pushed out from the heart of course begins to flow, but rather slowly. The shock wave, which constitutes the arterial pressure pulse travels much faster. Were it not for the effect of the vessel walls (boundary conditions) it would travel with the velocity of sound in the fluid. The fluid is, however, contained by elastic walls which give under the pressure wave, and in so doing slow it down. This velocity has been studied for its biophysical interest (King, 7; Hamilton, 6) but its variation, if any, with stimuli to the individual have not been investigated. The velocity would depend, as biophysical analysis shows, on the mean arterial pressure and on the elastic distensibility of the arteries. King presents data which show, for the aorta, a nearly linear relation between mean arterial pressure and pulse velocity within the normal range of pressures. His data also show a nearly linear relation between β, an inverse measure of the distensibility of the arterias, and the velocity over the normal range of β. Thus velocity increases as a function of mean pressure, and as a function of age, for β is greater with greater age. King is of the opinion that the velocity can be used as an index of β, and by implication, of mean pressure. Hamilton advances certain objections, which seem however to bear more on measurement of absolute values than they would on measurements of change.

Investigators have been interested in measuring the "permanent" state of a patient's arteries by this means. It may be that the measure will serve even better for the measurement of changes produced by stimulation of the individual. It would measure, of course, a combination of variables: the pressure and the resistance of the artery walls. Both may be expected to vary, though pressure is probably the dominant variable within the individual. The measure would be more sensitive with older persons than with younger for variations would produce greater effects when pressure and β are high to begin with, as they are in older persons. Since a very high proportion of the time for pulse propagation is taken in traversing the large arteries, it would be variations in their elasticity which would be reflected in the measure.

Technically the time between the heart systole and the arrival of the pulse at the periphery is quite easy to obtain. In a record showing the EKG and the volume pulse from the finger (recorded by the plethysmograph described below) one has but to measure the time between the peak of the cardiogram and the peak of the pulse wave. Since this is about .3" the paper speed needs to be rather rapid.

Blood Flow and Peripheral Resistance Measures

To measure blood flow directly it would be necessary to insert a cannula into a vessel. But if one measures the volume or diameter of some member, a finger for example, he will have an index of the amount of blood present in the region at the time, since changes in volume are produced by increases and decreases in the amount of blood contained in the vessels. With a given pressure, then, the rate of flow would vary as a function of the amount of blood at a point at a given time. In this measurement one has first obtained an index of resistance, which is inversely related to the fourth power of the diameter of the vessels (Poisseuil's law), then, given a knowledge of pressure by some other means, derived the flow from the two. The two measurements made here, in other words, are most closely related to pressure and resistance, and it would be preferable to leave the measures in these terms, rather than attempt to compute the flow.

The plethysmograph, or volume measuring instrument, has of course long been known in psychological laboratories in one form or another. Apparently the inconvenience and inaccuracy of the hydraulic and pneumatic models prevented very wide use by psychological experimenters. Its neglect is unfortunate, since the constriction-dilation of the small vessels is perhaps the most important variation in the circulatory system.

The electrical impedance plethysmograph described by Nyboer (12) seemed to offer convenience, accuracy and sensitivity which would facilitate this sort of investigation. The basic principle of the instrument is to pass a high frequency current through the tissues of some part, and to measure the impedance the tissues offer to this current. The high frequency would eliminate polarization of the tissues by the current, and their impedance would be expected to vary with the distance traversed by the current. (The high frequency would also prevent the g.s.r. from entering the record.) Nyboer demonstrates that with electrodes located longitudinally on the finger, increased volume (increased cross sectional area) would proportionally diminish the impedance (assuming that the change is resistive only). He presents a volume pulse record taken by mechanical means (presumably an accurate one) and an identical one secured by the impedance plethysmograph.

We therefore constructed two Nyboer plethysmographs, but immediately ran into difficulties with them. The design is apparently predicated on the supposition that tissues are non-reactive resistances or at least have little reactance. It is well known, however, that there is a substantial capacity vector in tissues. For this reason, apparently, we were unable to bring the instruments to an initial balanced state. As Nyboer describes the operation of the device it is comparing the impedance of two segments of tissue, rather than comparing one with an objective standard. (This may be the mean by which he secured a balance.) Used as he describes possibly the instrument could be balanced, but with considerable loss of information. Since the instrument seemed needlessly elaborate and complicated to operate anyway, we devised a revision of the circuit. It turned out that the parts used in building the original two instruments were enough to build four new circuits, with some extras left over. As in the Hyboer circuit, the measuring current is devised from an r.f. generator (135 kc), shown in Fig. 5 around the tube. From here we depart from the earlier plan. The voltage from the generator taken off through the transformer T1 is applied across S and a series resistor of 1000 ohms This voltage will, of course, be distributed over S and the fixed resistor, R, in proportion to their impedances. If S has an impedance Z the voltage across him will be $\frac{Z}{Z+R} \times E$, E being the applied voltage. Z being small in relation to R, we may simply say that the voltage across S is proportional to Z, his impedance. To eliminate phase shift effects the next operation of the circuit is to rectify this voltage by the tube 6H6. Then, because the voltage is quite large with respect to its fluctuations, in which we are interested, a part of it is opposed by an opposite voltage taken from the cathode circuit of the next tube (6SJ7). The algebraic sum of these voltages is then put into the 6SJ7 for amplification. The meter located in the output of this tube indicates how the opposing voltage in the input circuit should be adjusted. The size of the output current which corresponds to its optimal input bias was determined when the instruments were constructed. For one of the instruments, for example, it turned out to be 160 ma. So when an S was first introduced into the circuit the operator adjusted the opposing voltage until the meter read 160 ma. When readings of total impedance were desired this was done by manipulation of a calibrated potentiometer (Helipot) shown in the diagram. This setting will not need to be changed during a sitting in most cases.

From the output of the 6SJ7 there are divergent paths which can be operated at the same time. One is a direct coupled pathway which will record all changes occurring in S's impedance. (It is most useful for long term drifts, and might be more convenient if the pulse variations were eliminated by a shunting condenser.) Since these slow changes require further amplification they are passed on to one of the standard direct coupled amplifiers (see later section). Before the output of the 6SJ7 could be handled by these, however, another neutralization had to occur to eliminate a large unvarying portion of the output. This is the purpose of the bucking battery working into a potentiometer shown in the diagram. This potentiometer setting constitutes a permanent adjustment so long as the battery and tube remain the same.

But, on occasion, we are interested i. the pulse wave itself, rather than in the slow impedance drifts. For th. purpose it is more convenient to use capacity coupling than direct coupling in subsequent amplification. Hence the second pathway out of the plethysmograph. Though a coupling condenser it leads to a voltage amplifier of standard design as shown in Fig. 6. The time constant of this amplifier was a matter of compromise. The first arrangement was for a time constant of 0.1 second; this produced something like the first derivative of the pulse wave, which would be hard to interpret for some purposes. Going to the other extreme the next arrangement had a time constant of 2". With this the slow drifts would also be transmitted to some extent; they would block the amplifier with an overload and a long period would ensue before it regained equilibrium. The compromise was for a time constant of 1/2". This seems to give a fairly accurate picture of the more rapid rising limit of the pulse wave, although it does distort the slower descending phase somewhat. See Fig. 7.

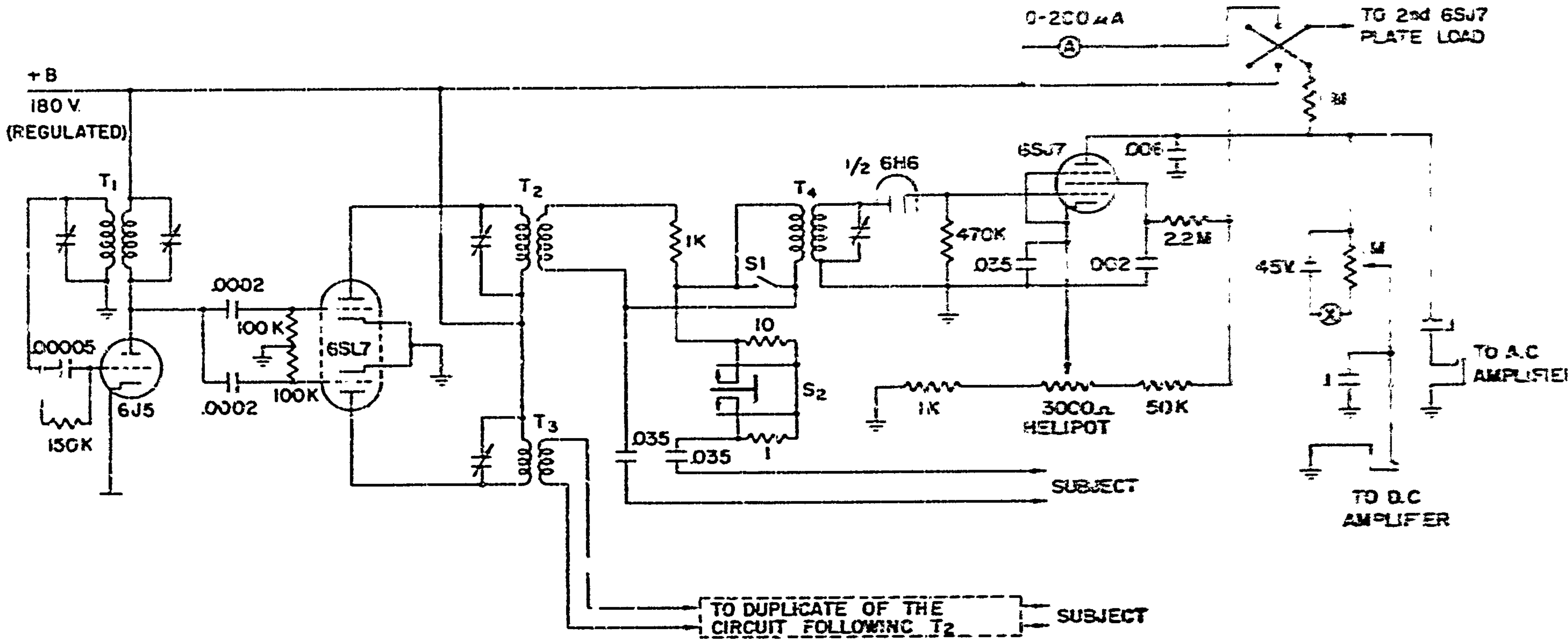


FIG. 5 IMPEDANCE PLETHYSMOGRAPH

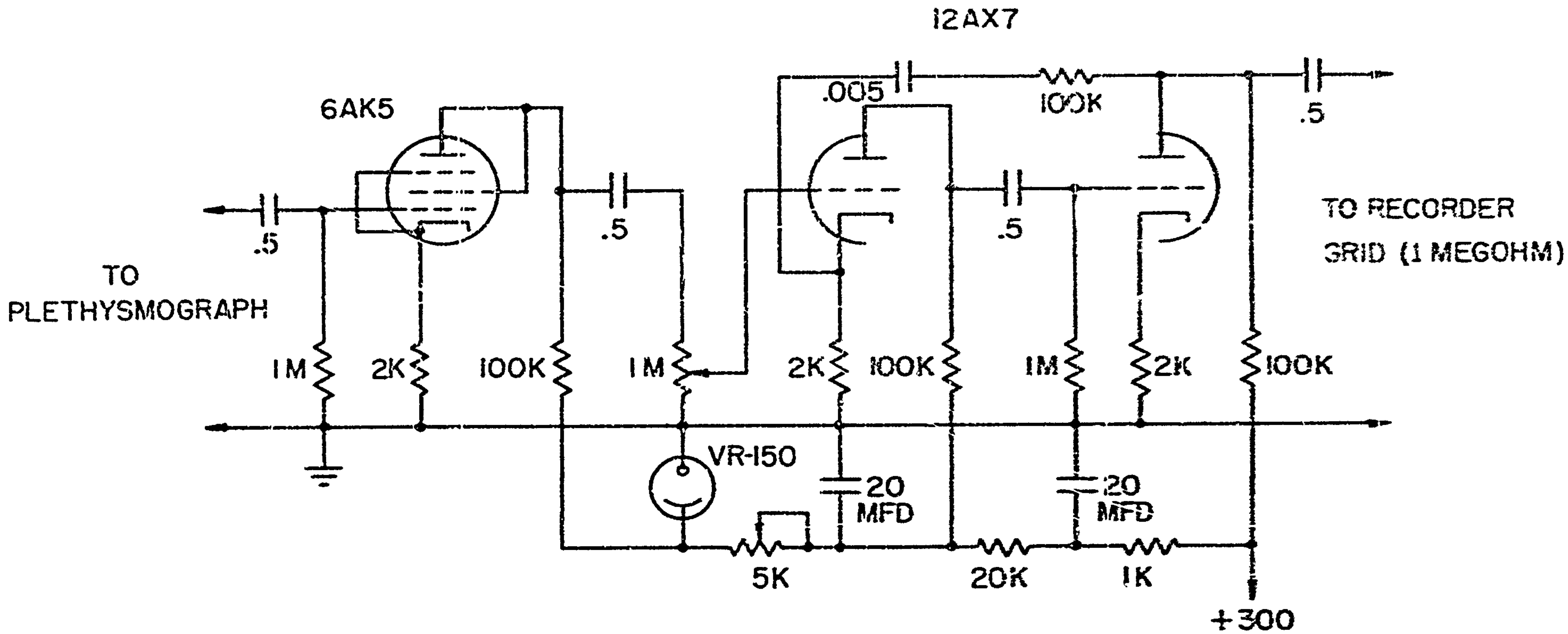
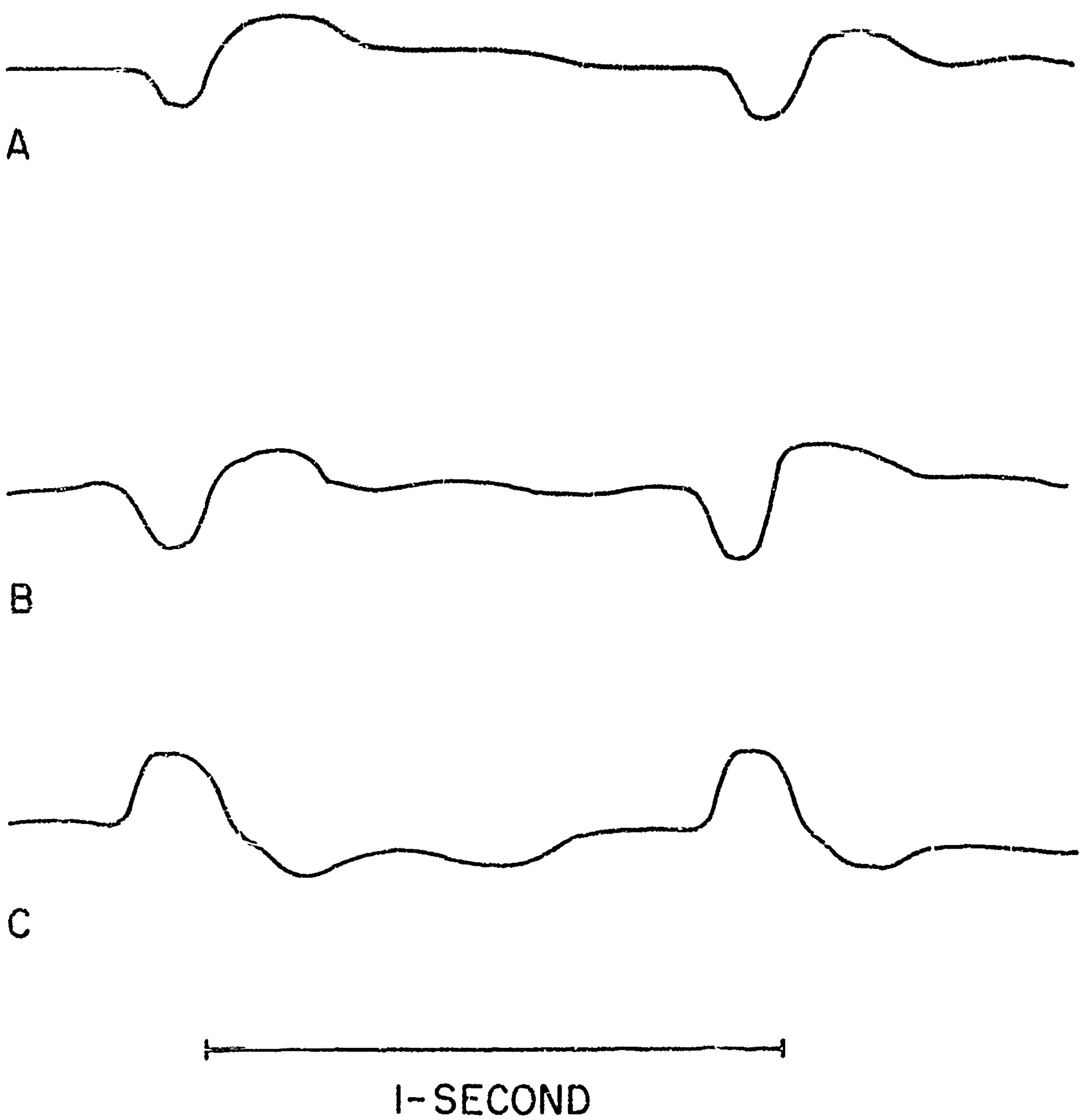


FIG. 6 PULSE AMPLIFIER

FIG. 7

VOLUME PULSE FROM THREE DIFFERENT ELECTRODE LOCATIONS (SEE TEXT)



In our use of the instrument we placed the electrodes (flat drops of solder) on the front and back of the finger tip instead of using the longitudinal arrangement as Nyboer describes. The mathematical analysis of the volume-impedance relation is more complex in this case, for if the finger is treated as a cylinder with equal expansion from the axis (Nyboer's analogy) the impedance would not vary with the volume and no pulse or other change would be detectable. As a matter of fact, of course the pulse and other changes do show with this lead disposition and about as readily as with longitudinal leads. The direction of the wave is inverse: Fig. 7 juxtaposes records taken from the same S at different times with three types of leads. Line B comes from the arrangement used in our experiment. Line C was taken from longitudinal leads, and it is clearly the mirror image of B. Nyboer's analysis indicates that the variations in C would be inversely proportional to volume. Those in line B would seem, therefore, to be directly proportional to volume, or nearly so. Line A in Fig. 7 shows the pulse wave with the electrodes on a transverse axis of the finger; i.e., from side to side. The wave form and sign seem to be identical with those of Line B. The basic physical theory of an impedance change which would show these phase relations remains to be worked out.

In attaching electrodes we applied a small amount of standard electrode jelly to the areas with which the electrodes would form contact. With electrode jelly all round the finger, and sometimes if no jelly at all is used the form of the pulse wave is changed substantially. The probable interpretation is that a surface pathway whose impedance compares with that of an interior pathway acts as a shunted capacity, or more likely perhaps, as a resistor shunted across the capacity of the finger.

In certain experiments we have used the direct coupled type of recording to show the slow volume changes; in others we have used the capacity coupling to bring out the pulse wave only. The two methods would be expected to give the same results. In the one case the measurement gives the amount which the elastic vessel walls are distended under a more or less steady pressure: the diastolic. In the other case the measurement gives the amount of additional dilation produced by the increments in pressure supplied periodically by the pulse. The one will on the average test the pressure volume function at a slightly higher level, but it would probably reveal much the same coefficient of elasticity (a coefficient which varies under neural influences).

A special method of measuring blood flow has been proposed by Abramson (1) and used by Lacey (8) in psychological investigations. The technique is to apply instantaneously to the base of the finger enough pressure to occlude the veins but not enough to occlude the arteries. The effect is to make a closed sac of the vasculature of the finger, with the arterial pressure sufficient to force blood into it until it is dilated to the point where the opposing elastic pressure of the vessel walls is equal to the pressure in the arteries leading in. It is possible to measure the amount of blood flow into the sac (increase in sac volume) during say, the first cardiac cycle after occlusion, and take this as an indicator of the normal blood flow. It is also possible to use the time for filling the sac and the amount of its distention as measures of circulatory conditions.

The electrical analogy for the system would be a condenser with a leak (to represent venous outflow) with an e.m.f. applied to the terminals. With the pressure cuff the leak is cut off. One observes, then, the rate of accumulation of electricity in the condenser. One could in addition observe the total accumulation and the time required for that accumulation to take place. All these measures should give information about the applied e.m.f. (the arterial pressure), the capacity (distensibility) and their combinations.

Such a method (the venous occlusion technique) would be an alternative, though it would not seem the only way of solving the problem. One could, of course, measure the characteristics of a circuit in which the condenser has a leak (fixed resistor) and expect to get the same constants he would if the leak were removed. So one might expect to get the same results from measurements made in the ordinary "dynamic" condition of the circulation, as would come from the more elaborate technique of producing a temporary stasis.

In our experiments we used on certain groups of subjects an applied pressure around the base of the finger which had triangular rather than a square wave form, and rose to such a height as eventually to occlude the arteries as well as the veins (see Fig. 4). It would seem however that much the same analysis would apply. The arterial pressure applied to the reservoir would decline in linear fashion and over the period involved would average 1/2 of the undisturbed pressure. The final quantity contained by the reservoir would therefore be less than that produced by full pressure, but the measurements should be comparable with others taken by the same method. Similarly the rate of flow would be continually diminished because of the decreasing pressure. From one measurement to another however this would be constant, whereas the measurements would vary according to the volume elasticity of the reservoir.

The sort of record obtained from our experimental arrangement is shown in Fig. 8. The total volume curve begins to rise about 1½" after the application of pressure begins, a point which is doubtless representative of the venous pressure. It rises in somewhat stepwise fashion in the successive pulses until a point of equilibrium is reached at about the same time that the pulse (upper line) disappears. A little after the point where the external pressure starts rapidly down there is a slight further increase in the total volume. Doubtless this indicates that the artery has been opened, allowing fairly high pressure to operate. In about a second, then, the total volume declines rapidly, indicating that the veins have now been opened and the system is returning to normal equilibrium. In the record we have measured three time values: Time A "Distension Time", from the onset of external pressure to the point of maximum distension; Time B "Time to Venous Release", from the beginning of pressure release to the beginning of the decline in volume; Time C "Equilibration Time", from the beginning of this decline until a normal equilibrium is established, as represented by a straight line. In addition, the amount of distension was measured.

If the foregoing analysis is correct the Amount of Distension should reflect the blood pressure and the distensibility of the vessels. Distension Time should represent only the latter. (Time taken to charge a condenser is independent of applied voltage.) The Time to Venous Release would be a sort of complementary measure of venous pressure. The Equilibration Time would seem to measure the same function as the Distension Time.

In certain experimental situations we computed the ratio of the Distension to the Distension Time. For the various experimental conditions the mean ratios (presented elsewhere in this report) were practically identical. Theoretically one would expect such a ratio to reveal variations in pressure. As they do not, there is additional reason for believing that

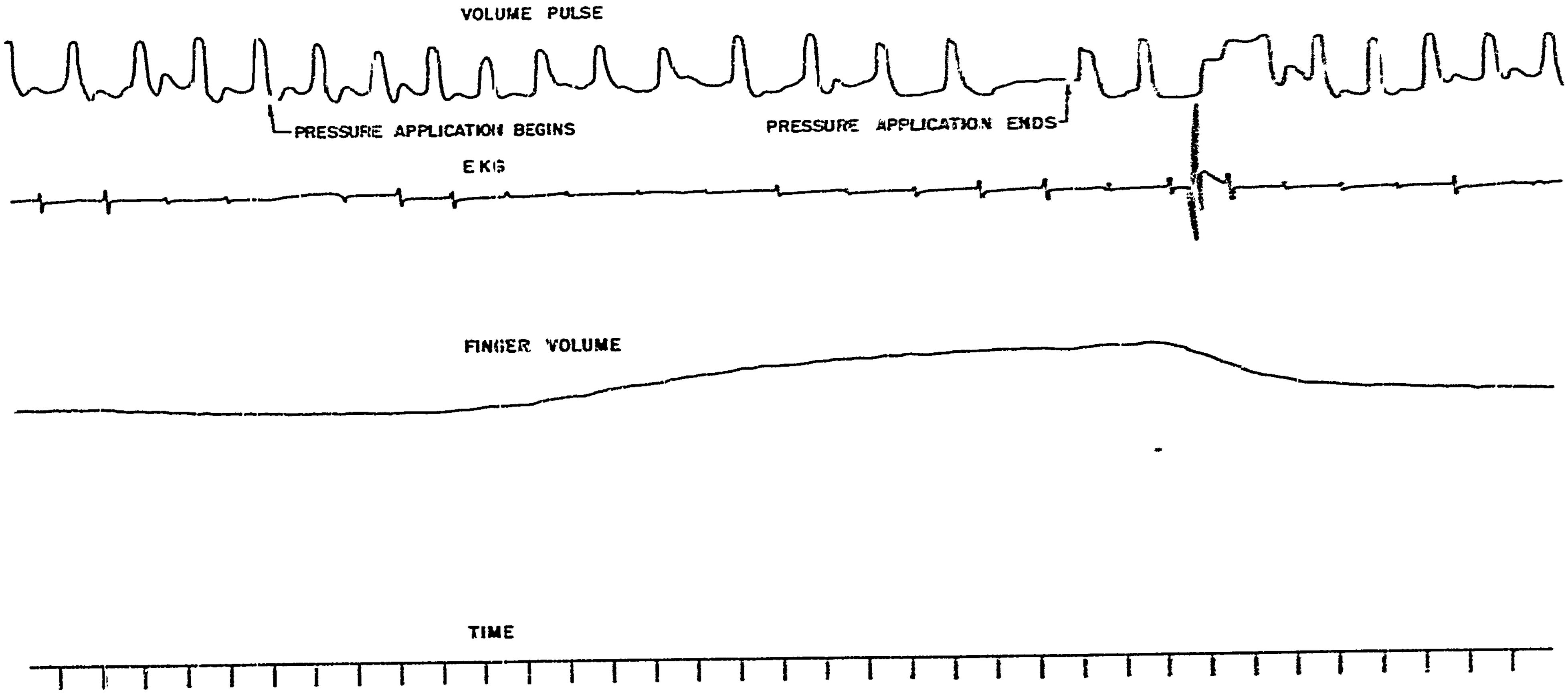


FIG. 8 CARDIO-VASCULAR MEASURES DURING APPLICATION OF OCCLUDING PRESSURE

pressure variation plays but a small role in the distention, in comparison to that played by vasoconstriction.

Measurement of Volume Changes by Recording Temperature Variations

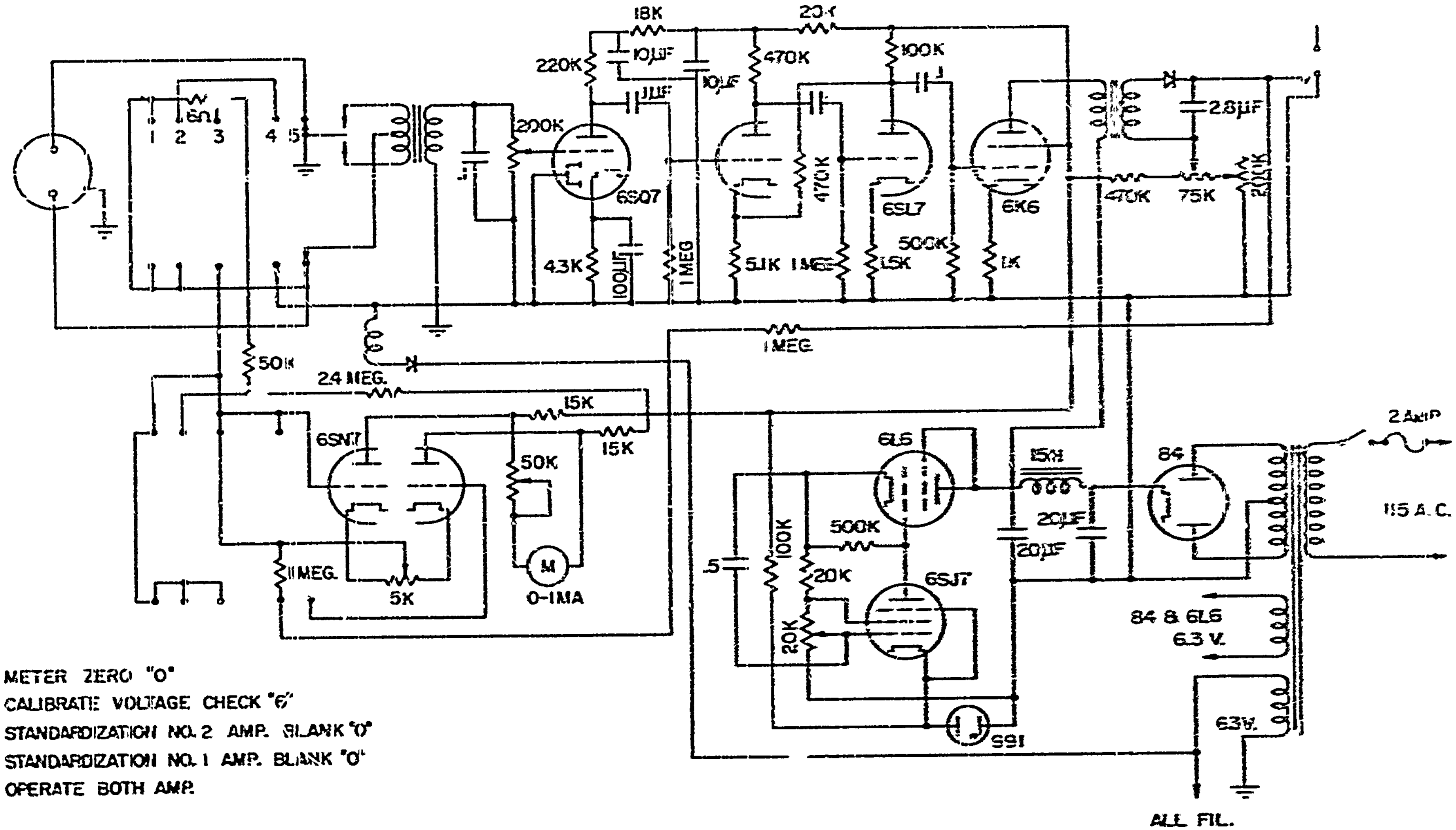
Under standard conditions the temperature of the skin is believed to reflect the amount of circulation in it, and in the whole underlying region. There is under normal conditions a temperature gradient from the interior of the body to a point somewhere distant from the skin. The slope of this gradient will vary with the heat insulating properties of the various tissues and with the amount of water evaporated from the surface of the skin. The flow of heat along this gradient, of course, tends to diminish the gradient; it is maintained by the delivery of more energy to the high point. Since the temperature of arterial blood is about constant, the more blood there is coming into the region the greater the flow will be and the higher the temperature at a given point.

There are evidently a number of other factors which would affect the temperature reading at a point, however. Ideally there should be a terminus for the gradient having a constant temperature maintained in spite of variations in heat flow. The evaporation of moisture from the skin will depend upon the atmospheric conditions of temperature, moisture content, and ventilation, as well as upon the amount of moisture produced. Aside from conduction there will be heat loss from the body by radiation as well as by conduction, with radiation varying with temperature in a different fashion from conduction. The importance of these disturbing factors can be assessed only through experiment. Some of them can be controlled with sufficient pains; others cannot.

We have taken records with a temperature measuring device in certain experiments. The transducer was a thermocouple in contact with the inner surface of a finger. The signal from this was carried to the amplifier whose design is shown in Fig. 9. Since the signals of interest were rather slow ones, it was necessary to regard them as direct current states. Being small they required considerable amplification more than is readily secured by direct coupled amplification. The design therefore was to interrupt the signal with a vibrator (60 cps), thereby converting the direct current into pulses whose size would be proportional to the signal. These could then be treated as alternating current, and amplified with a resistance-capacity circuit, as shown in Fig. 9. After amplification the signal is again converted to direct current by rectification. For convenience this system is provided with a means of setting the output at a pre-determined zero point, and a device for introducing a test signal into the circuit for calibration purposes.

This circuit served as a pre-amplifier for a direct coupled amplifier with automatic re-set (described elsewhere in the report). This sort of device was almost a necessity because there were in many S's long drifts in temperature, of uncertain origin, which would frequently bring the recording device to the end of its scale. Still further amplification was necessary to make the output of the direct coupled amplifier drive a recording pen, (also described elsewhere).

To maintain something like constant temperature conditions the S's room was cooled by an air conditioner to a temperature of 72°.



1. METER ZERO "0"
2. CALIBRATE VOLTAGE CHECK "6"
3. STANDARDIZATION NO. 2 AMP. BLANK "0"
4. STANDARDIZATION NO. 1 AMP. BLANK "0"
5. OPERATE BOTH AMP.

FIG. 9 AMPLIFIER FOR THERMOCOUPLE

Though general observation of our records indicates that the disturbing factors play a pretty large role in the measurement, it is possible that the method may be of some use in the study of vascular responses.

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CHAPTER XIII

BREATHING RESPONSES: PHYSIOLOGICAL RELATIONS AND RECORDING TECHNIQUES

1. Physiological Mechanisms

Breathing movements were one of the earliest interests of experimenters on emotion, and this variable was the first of the bodily changes to receive experimental study for the purposes of lie-detection (1). It still constitutes, of course, one of the three variables of the conventional "lie-detector".

In the early days interpretation of breathing movements seemed to depend a good deal on aesthetic considerations: symmetrical and regular breathing was regarded as normal. Henry (3) actually applied an aesthetic formula he had invented to the evaluation of breathing curves. Even up to the present time psychologists have paid no attention to the role which breathing changes may play in the physiological economy. For the understanding of "emotional" responses and for their practical use in the detection procedure such knowledge seems necessary.

The respiratory movement system operates so as to produce a periodic enlargement of the thoracic cavity by outward movement of the chest wall, depression of the diaphram and outward displacement of the abdominal wall.* The nervous mechanism which maintains this periodic action consists of three main parts. In ordinary breathing the respiratory center in the medulla produces a train of impulses, generated in the center itself, which upon arriving in the thoracic and abdominal muscles tends to produce inspiration. Operating by itself this mechanism would produce a continued distention of the thorax. But its output is modulated by the operation of two negative feed-backs with time constants such as to produce an overall oscillatory system. The first of these is activated by pressure receptors in the alveolar walls which set off the responses known as the Hering-Breuer reflexes. A distention of the walls will activate a reflex, whose afferent path is over the vagus, which inhibits the output of the inspiratory breathing center, so that the muscular contractions are reduced and the chest cavity returns elastically to its normal size. In case the Hering-Breuer reflex is especially large reciprocal action is also elicited from an expiratory center adjacent to the inspiratory, and the reduction of the chest cavity is speeded up. The second modulating feedback operates in the same fashion, parallel to the Hering-Breuer reflexes, but its mechanism is wholly neural. The pneumotaxic center in the pontile region evidently receives impulses directly from the main breathing center and feeds back inhibitory and reciprocally acting impulses to it with a certain time lag.

The normal breathing movement cycle is asymmetrical, with a shorter inspiratory phase. At the end of each expiration there is normally a brief period of rest, with perhaps a slight movement in one direction or the other. Thus the cycle may be said to consist of three phases, inspiration, expiration and rest, though the exact boundaries would be hard to distinguish. During phonation, of course, the form of the breathing movement is greatly altered. Since sounds are produced almost wholly by expired air the time of expiration tends to be maximized.

* For the basic physiology here summarized, reliance has been placed upon the accounts in (2, 5, 6).

The characteristics of breathing movements are subject to wide variations. In rate, however, wide fluctuations are found principally in disease conditions. Moderate exercise, on the other hand, produces an increase of only 10% in breathing rate (2). Depth of breathing, and, of course, the ventilation per minute varies greatly even in the normal individual, moderate exercise raising the intake per cycle by a factor of 7.

The inputs to the breathing system which initiate these changes are not well understood. Certain effects are known, but none seem large enough to account for the size of the changes. Chemical regulation is, of course, of considerable importance. The CO_2 content of the blood has a direct action upon the respiratory center increasing depth of the breathing. Because of this input, any disturbance in total ventilation will tend to be followed by its opposite. In hyperventilation the CO_2 in the blood is reduced, and other things being equal a period of hypoventilation will ensue.

Inputs to the breathing system are known to come from the chemical receptors of aortic and carotid sinus complex, so that the regulation of breathing by blood CO_2 is doubly determined. Muscular activity is believed to initiate reflexes which increase the activity of the inspiratory center, and, quite possibly the excitation of any sense organ, (or a change in its excitation) has a similar effect. Since breathing movements can be controlled "voluntarily" until the blood CO_2 reaches certain limits, it may be inferred that there are pathways over which inputs coming through the cerebral cortex can reach the respiratory center. In conditions when the organism manifests signs of autonomic activity there seem to be, typically, breathing changes as well, though not all breathing changes are directly related to autonomic action. One might expect therefore some direct connection between the autonomic system and the breathing system.

The general character of the inputs to the respiratory movement system may be suggested by an electrical network analogy. One may think of the inspiratory center as generating a carrier frequency, which is rectified and summed over a period of time (by the skeletal muscles). (Of course the manner of conduction in an electrical network is different from that in the nervous system, but this seems immaterial for the present purpose.) The rectified output is then carried back to the generator and modulates the signal through an output value. This feed-back should be considered as great enough so that no steady equilibrium will be established. The carrier frequency therefore has a slow wave imposed upon it, actually enough to cause its complete obliteration when the feed-back is conducting maximally. The network would be that of an automatic volume control circuit adjusted to a point beyond its critical oscillation frequency so as to produce a "motorboating" effect, the analogue of the breathing cycle.

Suppose, now, that the power of the generator is increased. The effect would be to increase the size of the "motorboating" waves. But it would not change their frequency, for this would depend only upon the constants of the network, not upon the input to it. The analogy would mean that increasing and decreasing the activity of the respiratory center by chemical means or by neural influences from outside the breathing system could change the depth of breathing, but would not affect its rate. Nevertheless rate changes do, of course, take place, and the inference is that the constants of the feed-back circuit are somehow changed.

In some pulmonary and cardiac diseases the receptors for the Hering-Breuer reflexes are sensitized (6). Such a condition would result in an increased frequency of the breathing rhythm as well as decrease in depth. Sensitization, that is to say, changes the constants of the feed-back circuit, and this may be one point of input for respiratory modification in the normal individual likewise. Of course change in the excitability of the nervous pathway involved in the feed-back would have the same effect.

If there is an increase in depth of breathing the neural expiratory mechanism may be put into action by stimulation of receptors in the alveoli whose threshold is not normally reached. This is, in effect, to add an additional feed-back circuit to the system, and the increase in feed-back would increase the frequency of breathing, because expiration would be faster, and inspiration would be set off sooner. Some acceleration of breathing would therefore be produced by increased depth, and this is undoubtedly what happens during exercise in part.

These two mechanisms would produce different frequency-amplitude relations. Sensitization of feed-back would produce shallow rapid breathing, while bringing into play of the second feed-back would produce deep and accelerated breathing. Though there is a serious lack of information about inputs to the breathing mechanism, particularly about inputs from the autonomic nervous system, it appears that they can be of both sorts, the one modifying the "generator", producing an amplitude change and a consensual rate change, the other modifying some part of the feed-back circuits, producing a rate change and an inverse amplitude change. The "voluntary" response mechanism can apparently modify either or both characteristics, since it is possible to duplicate by instruction to S any sort of breathing cycle, at least for a short time. Therefore, since rate and amplitude are related sometimes one way and sometimes another, it is desirable to consider them as two separate variables in specifying the response of the respiratory system. In considering the effects of respiration on the other hand one might wish to combine the two into a measure of ventilation.

The form of the breathing movement cycle has received a good deal of attention from psychologists (7) (8), with the $\frac{I}{E}$ ratio taken as a measure. It is obvious that vocalization by S shortens the time of inspiration with respect to expiration and to the total time of the cycle. There are a number of studies, summarized in the above references which agree in finding a relatively shorter expiration time in various emotional situations, though the number of cases is quite small and the situations are not well identified. Benussi, in a substantial number of cases found an increase in the $\frac{I}{E}$ ratio during lying. If the evidence for an increase is accepted there seem to be two mechanisms for changing the ratio. When the individual is vocalizing the sound producing system dominates other breathing regulators within wide limits, or, one might better say, the breathing system becomes a part of the sound producing system. In this case the I-phase is relatively shortened. A relative shortening of the E phase is more difficult to account for. A possible explanation is that certain stimuli ("emotional") produce deep inspiration, perhaps in one cycle only, perhaps in a series. Because of the depth of this inspiration the Hering-Breuer expiratory reflex is stimulated and expiration is forced and rapid. Or, similarly, certain stimuli may produce a diminished breathing movement for a few cycles (S "holds his breath"). The resulting O_2 deficiency and CO_2 excess will eventually produce a deeper inspiration, which in turn would stimulate the expiratory reflex, with the same effect on the E-phase. In either case the $\frac{I}{E}$ change is secondary to the deep inspiration. Another possibility is that the onset of the inspiratory phase is inhibited, and the delay counted as part of the preceding E-phase. If either of these is the explanation, the investigator may be relieved of the practically impossible task of measuring the $\frac{I}{E}$ ratio or I-fraction.

2. Devices Constructed for Recorded Breathing

In the present experiment three breathing records have been used. Two of these recorded displacements of the body wall; the third recorded temperature changes of the air in front of the S's nose and mouth.

To avoid the non-linearity inherent in a pneumatic system electrical pneumographs were used for recording body-wall movements. A small straight potentiometer of 300 ohms was mounted in a metal box about 3" square and 1" deep. A lever attached to the slider on the potentiometer protruded from one edge of the box. The box rested on S's chest or abdomen, supported by a band hung around his neck. A short cord from the lever ran over a pulley and was attached to a belt that encircled the chest or abdomen and was anchored to the box at its other end. Expansion of the body wall, it will be seen, moved the lever and the sliding contact on the potentiometer. A light spring attached to the lever and the mounting caused the lever to return to its original position when the body circumference diminished. Two of these units could be used at once, one on the chest and one on the abdomen.

Across the potentiometer of each unit a 3 volt e.m.f. was applied from a selenium rectifier. The signal was taken off from the negative terminal and the variable arm and carried to a direct-coupled amplifier unit with automatic re-set. The output of this was passed through a converter and power amplifier to a recording stylus. (For a description of these elements see the section on general recording apparatus.) The re-set mechanism of the d.c. amplifier operated when S had a particularly large inspiration or when he shifted position, but for the most part it was not called into operation. A record produced by this recording system is shown in a later section ("Procedure 6 and 7").

Picking up temperature variations from the air near S's mouth and nose seemed as though it might be a convenient way of recording the breathing cycle and might at the same time produce some new information.

For this type of recording S was required to look into the head piece taken from a stereoscope. A thermocouple was attached beneath the head piece so that it was level with S's lower lip. It was adjusted for each S so that it was about 1 cm. from the lip. Recording from this transducer was by means of the amplifier and associated equipment described in the section apparatus for cardiovascular recording.

Measures actually used in the experiments were the frequency and amplitude of breathing movements taken from the pneumographs, and maximum and minimum temperature in a given period of time in the case of the thermocouple record. For a few records taken during a lie-detection experiment an attempt was made to measure the inspiration and expiration times. The plan was to draw up a set of rules which clerical workers could follow in making these measures. It seemed to be impossible to make rules which did not require continual interpretation and additions as the work went along. The chief difficulty was handling the rest periods in the breathing cycle, for there are no clear demarcations between expiration, rest period, and inspiration. Frequently during a rest period there is a little slope to the line in one direction or the other. Because boundaries are defined by direction of movement, an almost indistinguishable change here results in an enormous change in the $\frac{I}{E}$ ratio or I-fraction. After several days trial therefore the attempt was abandoned. These difficulties may explain why investigators trying to use quantitative measurements of this sort in lie detection have come to such diverse results, and why lie detector operators apparently do not make explicit use of the ratio (4).

3. Comparison of Chest and Abdominal Breathing

Provision was made for recording the chest and abdominal breathing movements simultaneously on the hypothesis that stimuli might produce changes specific to one of these, at least in some individuals. To test this possibility 8 S's were run through the same procedure as used in the pattern analysis (see later section for description). Records were measured in the same fashion as used in that experiment so as to give a maximum-minimum difference in each 5-second period measured. Periods selected for measurement were two before the stimulus, and four beginning $2\frac{1}{2}$ seconds after the stimulus. Each S had four "neutral" questions, 8 dealing with taking money, and 2 threats of shock. The mean of each pair of periods was then obtained. A correlation was computed between chest and abdominal measures for each S. These r's were for the most part between .70 and .80. They seem to indicate that substantially the same information is given by the two types of record when some allowance is made for error of measurement. For the subsequent experiment, therefore, the abdominal breathing record was omitted, and the channel used for a different variable.

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CHAPTER XIV

PHYSIOLOGICAL BASIS AND TECHNIQUE OF ELECTROMYOGRAPHIC STUDIES

Although most studies of the disturbing effects of stimuli upon the individual have been directed toward changes in the vegetative processes, regulated by the autonomic nervous system, there seems to be no reason why investigation should be so confined. In fact the skeletal muscular system is often presumed to take part in an "emotional" reaction and to manifest varying states of tension. Facial expressions are, of course, obvious muscular responses; the startle response (Landis and Hunt) as a reaction to strong auditory stimuli is also well known. Auditory stimuli of less intensity also produce a muscular response, though evidently not an overt one (4). Malmo (8) has presented evidence that for certain individuals the neuromuscular system is the favorite channel for manifest neurotic symptoms.

Conceivably skeletal muscle responses may be quite general, amounting to a heightening of tension throughout the musculature, or they may consist of particular responses (tics, for example) which tend to occur under all circumstances. They may also consist of patterns of muscle excitation more or less peculiar to an inciting situation, and immediate state of the organism, just as effective overt movements do. All gradations between these varieties are likewise possible. Which of these should be classed as "emotional" responses it is difficult and, probably useless, to decide. They are however physiological states and may be used to detect antecedents and predict consequences if the relevant relationships can be discovered.

The physiological mechanisms underlying muscular tension responses have been discussed in an earlier paper (1). In brief there is typically a simultaneous excitation of both muscles of an antagonistic pair, with activity not being confined to one particular pair (see also 5). The nervous channels producing the muscular excitation are those of the c.n.s. and evidently these have a certain amount of activity at all times except under rather special circumstances. This amount fluctuates rather widely with the stimulation of the individual, and varies in geographical distribution, as well as amount, according to the circumstances in which the individual is placed.

Muscular excitation, especially when too small or too equally balanced to produce movement may be recorded by picking up action potentials given off by muscle fibers, by means of electrodes on the skin surface. An electrode will pick up potentials from only a limited area because of the attenuation introduced by the fluid conductors of the body. Nevertheless the activity of a very large number of muscle fibers affects a given electrode and their combination would on the average give a zero potential. But of course recording is not "on the average" but of the moment: therefore one picks up the deviations from the average, which, there is reason to believe, would be proportional to the number and magnitude of the original voltages. These muscle fiber potentials increase in number and in frequency as the intensity of stimulation increases.

Since the combined output of a group of muscle fibers much resembles "noise", a mixture of all frequencies, it is advantageous to rectify and integrate these signals before they are recorded: total voltage seems the most significant variable.

The apparatus used in these studies is basically the same as that described by Davis (2) (3). It consists of five principal parts: amplifier, integrator, electronic discharging switch, phase inverter, recording stylus with power amplifier. Four independent channels of this sort were constructed for use in the present experiments.

Fig. 1 shows the circuit for each of the amplifiers. There are three stages in each, each stage being mounted in a removable can for convenience in repair work. The cans, as shown in the diagram, plug into the basic chassis containing the basic supply circuits and inter-stage connections. Each stage contains a pair of 6SJ7 tubes connected in push-pull. In order to achieve independence of the several channels from each other when they are connected to S, the first stage of each is operated ungrounded and with a separate power supply. For the first stages the power supply was from batteries to reduce noise effects. For the subsequent stages storage batteries were used for the heater supply, to avoid introducing 60 cycle hum, but the high voltages were satisfactorily supplied by a rectifier of standard design. There are two such rectifiers each supplying two channels. A step-wise gain control was provided for each amplifier.

The push-pull output of each amplifier goes to an integrator. The circuit design, shown in Fig. 2 is with slight modifications the same as that described previously. To the output of each integrator an oscilloscope was permanently attached. (Ahead of the phase inverter described below.) One axis of each was modulated by a 60 cycle sweep circuit. A four position switch made it possible to view, on the other axis, 1. the input to an integrator for test purposes, 2. the output of an integrator when it was receiving no input, for balancing purposes, 3. the output of an integrator when it was receiving a test (60 cycle signal) and 4. the output of an integrator when its input was the signal from the amplifier feeding it. When an S was being run the switch would be in the last position so that the operator could see events in S even when the graphic recorder was not turned on. Other positions would be used for preliminary adjustments.

When operating, the integrator would rectify the signal (by means of the 6H6 tubes), then allow it to affect the rate of accumulation on the 2 mfd. condensers shown in the diagram. This effect would be in opposite directions on the two sides of the push-pull circuit, and the potential difference between the two condensers would be proportional to the sum of the rectified signals.

It is necessary to provide a device for discharging the condensers periodically. This was accomplished by an electronic switch arrangement which provided a conducting pathway for this discharge every tenth of a second for a brief period. The circuit is shown in Fig. 3. An oscillator with a long phase and a short phase activates the discharge circuit of each short phase by causing a pair of triode connected 6L6's to become conductive. When these are conductive the voltage they apply to the tubes 2051 causes them to become conductive also, so that a discharge pathway is provided.

The potential difference across the accumulating condensers is not at ground on either side, nor can the circuit be connected to a further amplifier with a ground in the center, because the input grids of the amplifier would then be loaded with the condenser-ground difference, rather than with the condenser-condenser difference only. Hence the condenser-condenser voltage is put through a phase inverter circuit before it is taken to the subsequent

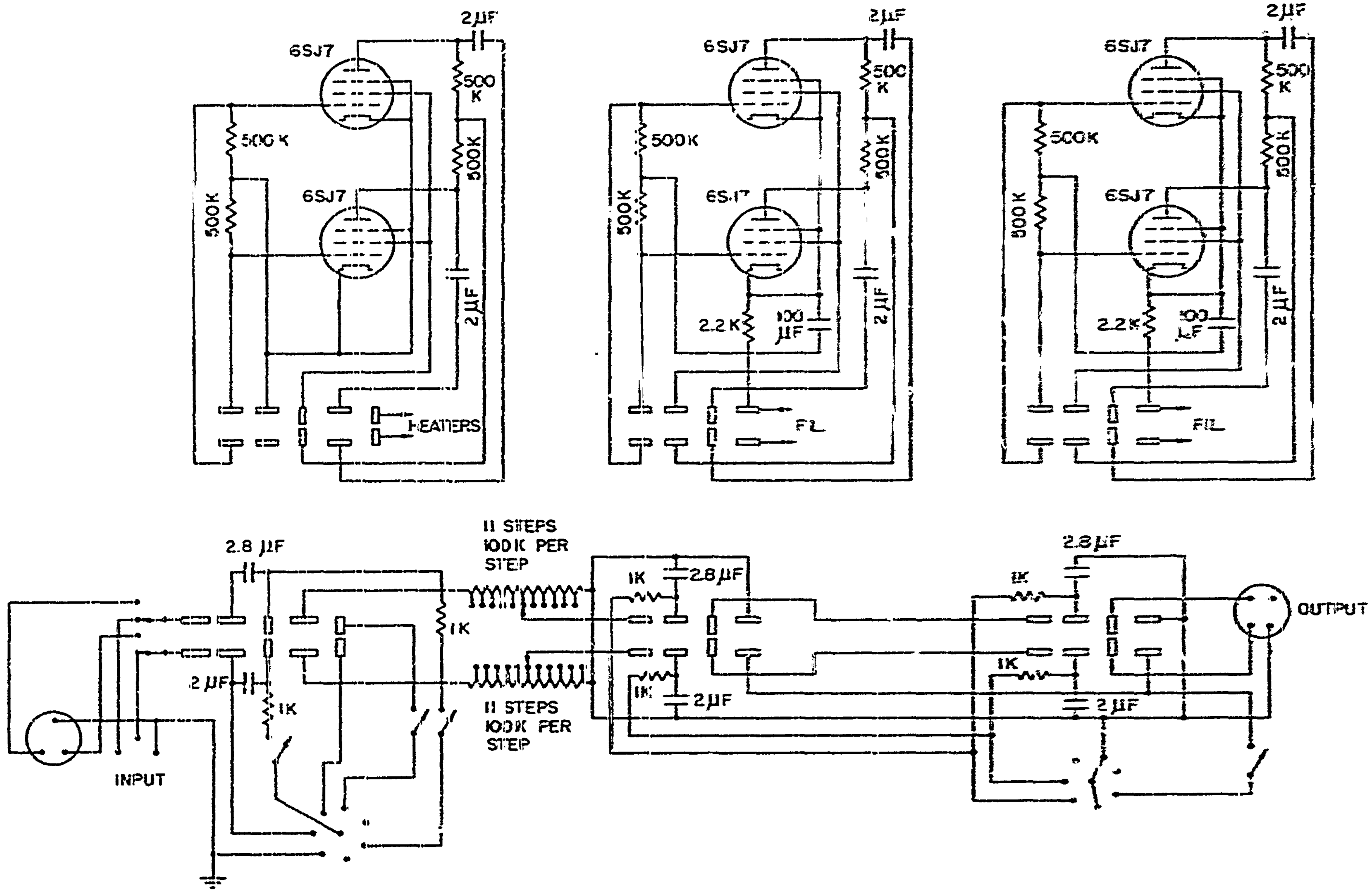

FIG. 1 HIGH GAIN AMPLIFIER FOR MUSCULAR ACTION POTENTIALS

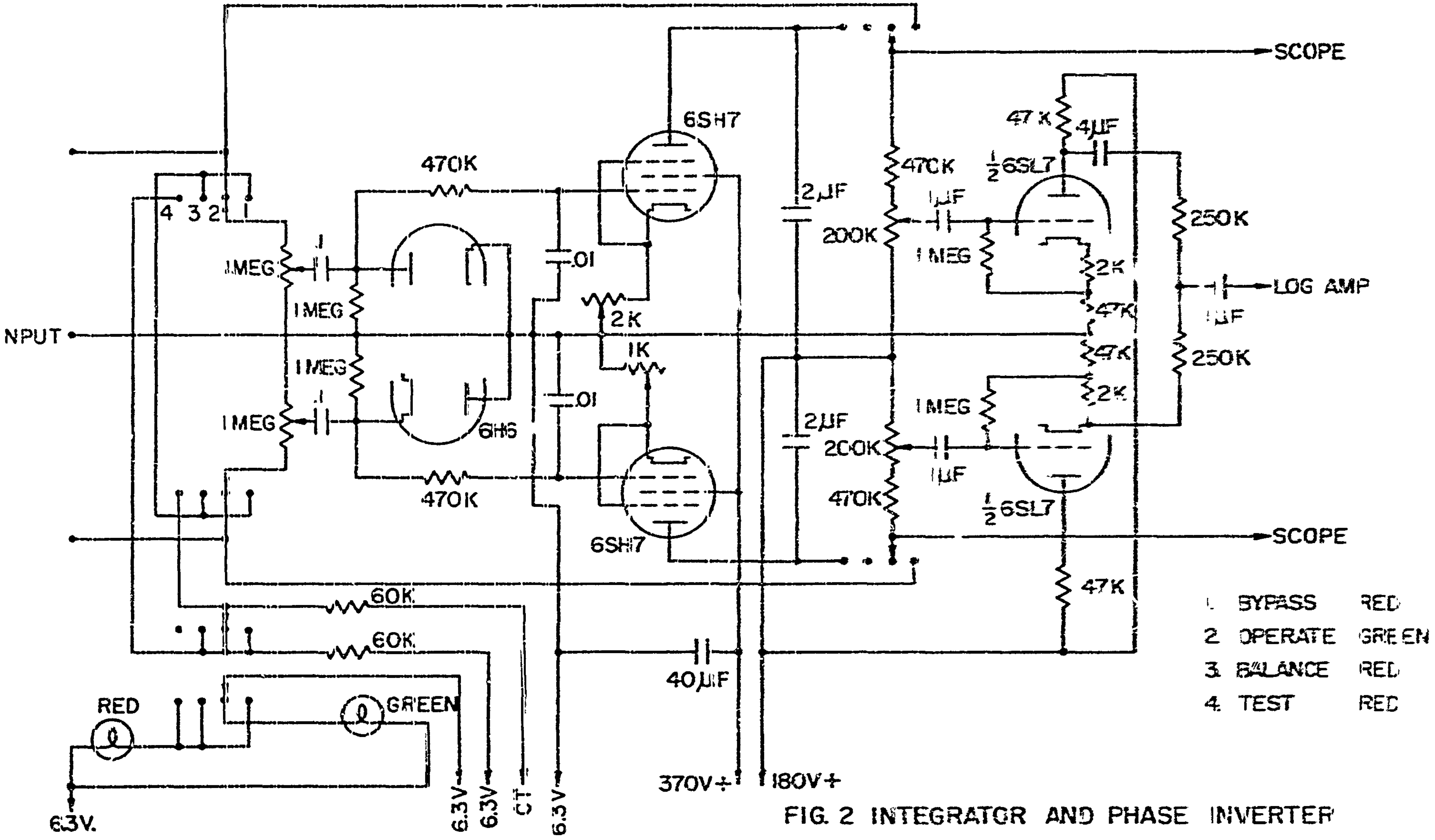

FIG. 2 INTEGRATOR AND PHASE INVERTER

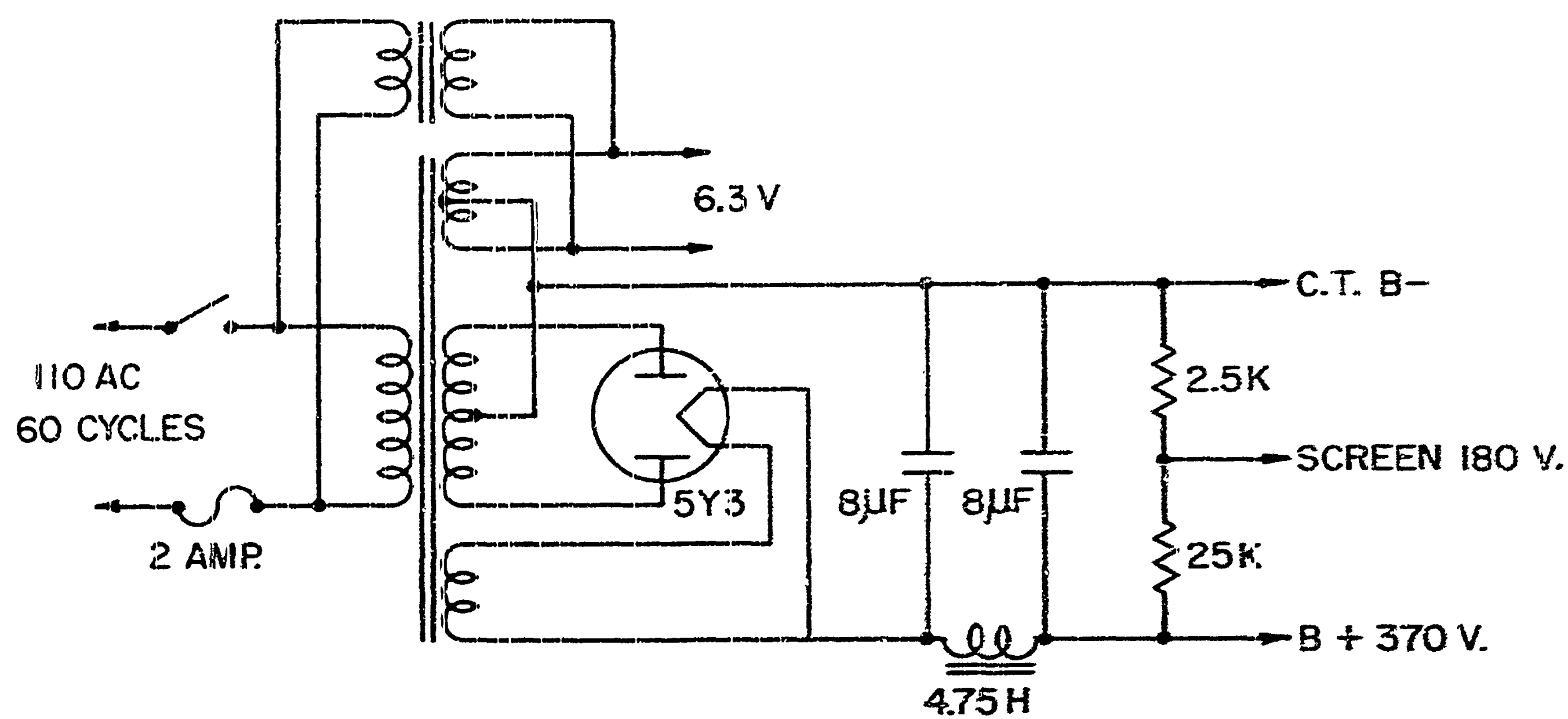

FIG. 2A POWER SUPPLY FOR INTEGRATOR

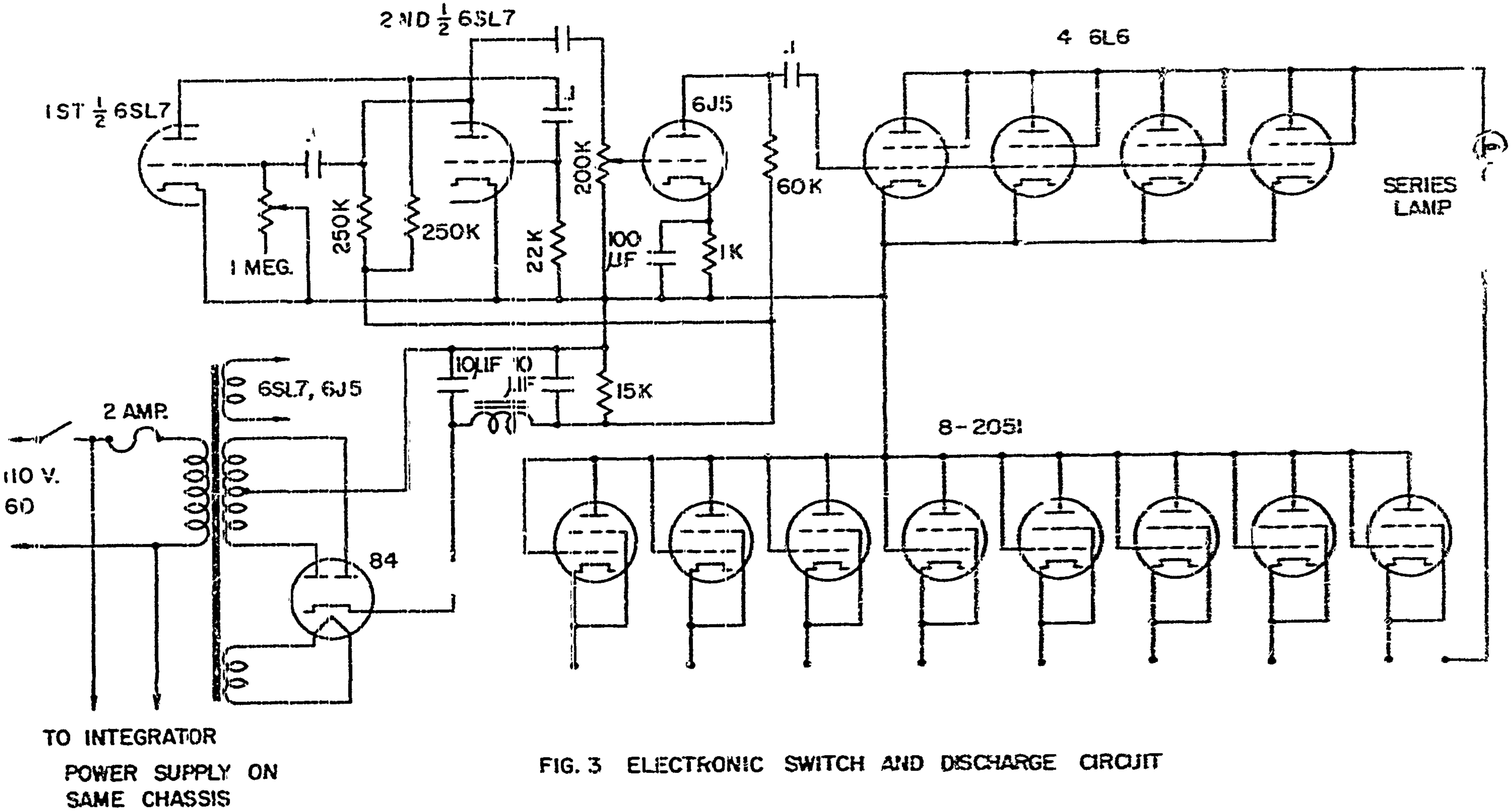

FIG. 3 ELECTRONIC SWITCH AND DISCHARGE CIRCUIT

power amplifier. By means of the phase inverter one side of the integrator output is brought to ground. (A second phase inverter converts the signal to push-pull, with center ground. See Section on General Recording Apparatus.) It is then put into a one stage power amplifier which serves to drive the recording stylus for each channel. (The styli and driving circuits are described in the Section on General Recording Apparatus.)

To calibrate the several action potential recording systems a commutator switch is provided in the input of each. For calibrating this is thrown to a position which puts a small known voltage at 100 cycles into the amplifiers. This signal is generated by a small oscillator with a measured output which is attenuated by a divider. This divider is provided with steps of known value so that a potential of 1-100 µv can be delivered. For coupling purposes this is passed through a 1-1 transformer (with no measurable loss) before it is introduced into the amplifiers. A calibration record was secured for each S for each gain setting used.

For statistical reasons it is desirable to have action potential values expressed in terms of log µv (6) one can determine the microvolt value and then convert it to log values. However when there is much data to be processed, a shorter method was used. Before each experiment an overall calibration curve for each channel was secured by introducing a series of voltages into them. The deflections of the styli (with integrator operating) were measured for each and plotted against the known inputs. It so happens that these points can be fitted about equally well with a linear and a logarithmic function. For convenience the log function was chosen; so that knowing the two constants of the fitted curve one could read a given deflection as indicating a certain log µv value: that is the deflection is proportional to the log µv input. (This relation fails below about .05 inch, where the deflections are too small to be of much use anyway.) When the gain of a system is changed the effect is, with the log scale, to add to, or subtract from, the value a given deflection is taken to indicate (rather than to multiply it). The amount that should be added or subtracted is determined from the check calibration made for each S for each gain setting. By adding or subtracting this, in hundredths of an inch, from the deflection measured in hundredths of an inch, one arrives at a value which is in K log µv. Figures in this form are used in the statistical analyses. When it is desired, say in a set of final means, they can be converted to log µv by $\frac{1}{K}$, whose value is given in the original fitted logarithmic calibration curve.

Where there were substantial numbers of records they were measured on a device known as a "Telereader". This consists of a carriage which will wind a record forward or backward at various speeds according to the pressure on a foot pedal and the setting of a number of push buttons. About a foot of record is exposed at a time. Light from mercury arcs is reflected from this through an optical system providing a magnification of $2\frac{1}{2}$ and focussed on a ground glass screen before the operator. There is a hair-line controlled by a wheel which is placed tangent to the record line at the point where a measurement is desired. A dial then reads the number of hundredths of an inch the point is from some pre-set zero. In taking measurements by the logarithmic system the zero point was pre-set according to the sensitivity indicated by the check calibration for the record in question. Thus the reading automatically adds in the constant which allows for the sensitivity of the recording system, and the dial on the Telereader reads in terms of K log µv directly.

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CHAPTER XV

TECHNIQUE FOR THE STUDY OF THE GALVANIC SKIN RESPONSE

1. Recording Technique

The physiological and physical-chemical bases of the galvanic skin response have been well ascertained (1) (3) (5) (6) though its nature is often misunderstood. In brief it depends upon the activity of the tissues in the sweat glands (not, as often supposed, upon the amount of moisture on the surface of the skin). These membranes are normally polarized, as are living membranes in general, and when a small electric current is passed through them they develop a condition of "electrotonus" in which those oriented in one direction are more polarized, those in the other less. As is also the case with tissues in general, excitation is manifested by a depolarization. The mechanism is the same as that for nerve membranes, but the speed of the phenomenon is very much less than that for most nerve fibers, though perhaps of the same magnitude as found in the autonomic division.

Most psychological studies have dealt with the palmar sweat gland responses (10). Excitation of these sweat glands is brought about by impulses over the sympathetic fibers, but the chemical mediator between the nerve and effector seems to be a cholinergic one such as would be characteristic of the parasympathetic system. The glands are therefore little affected by the presence of adrenalin in the blood. These facts make the response one of special interest in the study of autonomic action. So far as known it is a sympathetic response, not offset by parasympathetic action, and it is the one autonomic response of this character which is readily accessible. With a cholinergic mediator one can expect also that state of the tissues will not be complicated by long-term hormonal effects, since acetylcholine is an unstable and short-lived substance. The state of the glands should correspond more closely to the current action of the nervous system than would be expected in adrenergic effectors. The g.s.r. should be particularly useful, therefore, for the assessment of stimulus effects as is required in lie-detection experiments.

In recording the phenomenon one has a choice of two methods: the e-technique (Tarchanoff phenomenon) and the r-technique (Féré phenomenon). The former, by measuring the e.m.f. between two points on the skin depends upon the natural polarization of the tissues and its changes; the latter, by measuring the apparent resistance (actually the back e.m.f.) when an external source is applied to two points, depends upon the state of polarization produced by the artificial current. The latter is the easier and commoner technique and seems to have certain theoretical advantages as well. By inducing electrotonus one can effectually remove from the record the effects of all tissue polarization oriented in one direction, and so secure a measure of the magnitude of one phenomenon, rather than the difference of two opposed phenomena. The g.s.r.'s studied in the present experiments are all of the r-phenomenon variety.

There are certain requirements for instruments for recording this phenomenon if the results are to be subject to quantitative interpretation. 1. As with any instrument one should know the relation between the input and the output at all times. (Since this is sure to change from time to time, there should be provision for calibration.) 2. It should have a time constant not greater than .2". With a slower constant there would be danger of dynamic distortion. 3. It should indicate the total apparent resistance of S, as well as the changes it undergoes (g.s.r.'s) inasmuch as the relation between the two is of critical importance. 4. It should pass the same current through S regardless of wide fluctuations in his apparent resistance, since the recorded magnitude depends upon the current, but is not directly proportional to it (3).

Apparently none of the instruments now being offered commercially for lie detection meet all these requirements. With regard to certain of these specifications the manufacturers do not give any information. In certain early experiments we have used a commercial instrument, with consequent uncertainty about quantitative comparisons. For our principal experiments we have used specially constructed instruments which meet the requirements for quantitative work.

Fig. 1 is a schematic diagram of the circuit supplying the electrotonic current through S.* Voltage for supplying the current is derived from the 6.3 v winding of the transformer in a direct coupled amplifier (see section describing this). This is stepped up by means of a small filament transformer used in reverse. The current is then rectified and applied to the circuit consisting of S and the tube 6SH7, whose function is to keep the current constant. (S is in the plate circuit of this tube.)** By means of a double throw switch S may be replaced by a dummy subject for purposes of calibration. This dummy, as seen in the diagram, consists of a series of ten 500-ohm resistors, any number of which may be put into the circuit by means of a rotary switch.

In this circuit, since the current is constant, the voltage across S is proportional to his apparent resistance. Consequently a measurement of this voltage is a measurement of S's resistance. The voltage therefore is the signal which is carried to the input of a direct coupled amplifier with an automatic reset device (described elsewhere in this report).

In operation the amplifier will automatically adjust itself to its proper operating range as soon as it is connected to S. When it settles on this range, with the indicating pointer on the dial, the index number showing through a hole in the panel will indicate how many steps the rotary switch has advanced from zero. If the value of each step is known, the index number therefore shows the total voltage which the mechanism has applied to offset the S's apparent resistance. With a constant current through S this voltage is, of course, proportional to S's resistance. This is assuming that the indicating needle always comes to rest in the zero position. If it does not, and if a very exact measure of S's total resistance is required, the resistance value indicated by the departure of the needle from zero can be subtracted from that inferred from the index reading. (In the present

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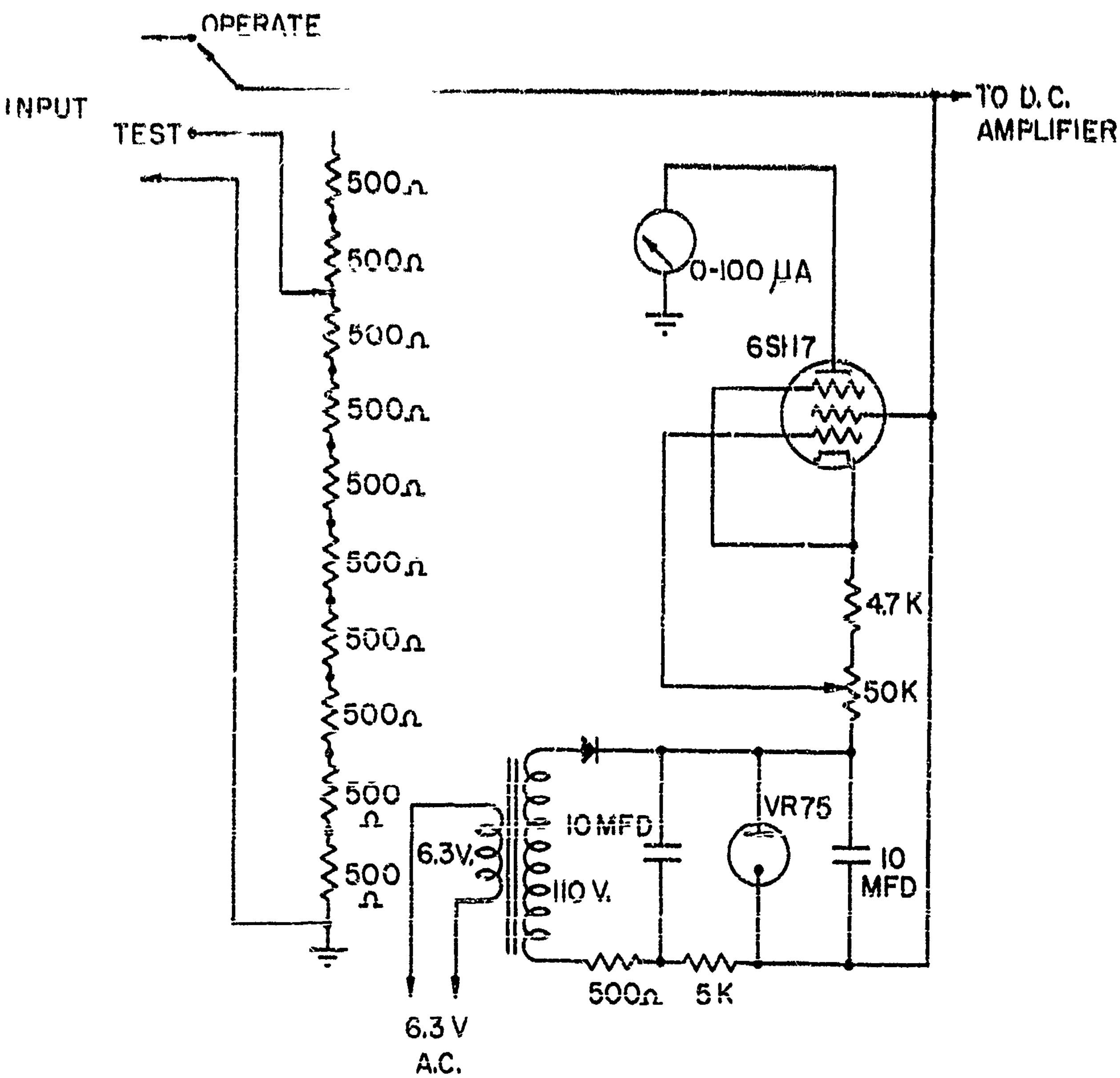
* Basically the circuit is that described by Davis and Porter (4).

** The electrodes used with this apparatus consisted of plastic caps about 1" in diameter. In the bottom of each lay a plate of Zn, to which the lead wire was soldered. Above this was a layer of MnO_2 soaked with normal salt solution, and on top of that in contact with the skin was a felt pad soaked in normal salt. S's skin was rubbed with electrode jelly prior to attachment of electrodes.

FIG. I CONSTANT-CURRENT SOURCE FOR G.S.R



use it was thought an unnecessary refinement to make this correction, since our readings were to be represented by two-place numbers in any case. See below.)

Once S has been inserted into the circuit and the mechanism has produced a reading on scale, the automatic re-set will keep it there. When the indicator reaches either end of the scale the mechanism will throw it back on scale again by adding or subtracting a constant voltage value. Thereupon the index on the panel will show a new number, indicating a new base level of resistance. On a graphic record taken from the instrument such a quick jump in level is easily distinguished from the slow g.s.r. changes, (see record in later section, "Procedures 6 and 7"). So, if one knows the base level at the beginning of a run he can ascertain it at any point in the record by allowing for the appropriate number of re-sets in each direction.

At the beginning of a sitting the experimenter must select the amplifier sensitivity which seems appropriate to the size of the responses S will give. He can, of course, change this during the course of a sitting though he will usually not need to do so. If, however, the S's total resistance is very high and the operator chooses a high sensitivity there is danger that the voltage across S may become too great for the available re-set voltage to neutralize. In this case the rotary switch that inserts the bucking voltage runs to its maximum position and, failing to bring the pointer on scale, keeps on turning, through zero, and around again and again. The operator must then reduce the sensitivity. It is fortunate that S's with high resistance will give large g.s.r.'s, in terms of ohms, so that a lower sensitivity is appropriate on both counts. If the sensitivity does not need adjustment while a graphic record is being made, the operator needs to pay no attention to the instrument.

The instrument should have its calibration checked frequently. There are three items that need to be checked in this calibration.

(1) The indicating meter should be made to read zero when there is zero input and zero showing on the index. A knob is provided on the amplifier for making this setting. Alternatively the adjustment can be made so that the indicating meter reads zero when there is no input and the index shows 1 or 2. In this case 1 or 2 is subtracted from all index readings taken during operation.

(2) The deflection of the indicating meter for a given change of input resistance should be ascertained. To accomplish this one turns the double throw switch to insert the dummy S, and increases or decreases the resistance of the dummy S by the 500 ohm steps provided, reading the meter for each, or getting a deflection on the graphic record which can later be measured. This determination is most conveniently made with the amplifier set at full sensitivity. If the sensitivity is less than full during a sitting the changes can be evaluated by applying the sensitivity constant to the values obtained by the calibration. (Sensitivities available range from 1-10 in equal steps.)

(3) The size of a re-set step should be determined. This is adjustable by means of a control on the panel, but it will ordinarily be set to produce a little less than a full scale jump on the indicating meter. To find the value one simply changes the input enough to make a re-set occur. The amount of change can be read on the indicating meter or on the graphic record and evaluated in the light of the response line obtained in Step 2. (Actually the value can be found from any re-set that takes place during an S's run.)

Quantitative readings are secured from graphic records as follows therefore:

1. To find the base level of resistance (usually before the application of each stimulus), one finds the index which was showing at the time, by starting with value noted at the beginning of the run and adding the algebraic sum of the re-sets that have occurred up to the point in question. This number is multiplied by the value of a re-set (Step 3 in calibration). This result is multiplied by the reciprocal of the sensitivity. (If greatest exactness is required the resistance indicated by the deviation of the line from zero may be subtracted from the result.)

2. To obtain the value of a g.s.r. the maximum displacement due to the reflex is measured. If the reflex has caused the line to reach its limit and caused the re-set to operate, the value of the re-set (in distance) is added to the measurement of the reflex. The value is then converted to ohms by means of the calibration (Step 2). The result is then multiplied by the reciprocal of the sensitivity setting.

The above procedure for measuring the g.s.r. presumes a linear scale. In the majority of our measurements, as explained elsewhere the scale was non-linear. In this case the procedure is the same except that the ohms indicated by each position of the line must be obtained from the calibration curve and the size of the reflex found by subtracting two such values (and adding the re-set value in ohms, where there is one) rather than by measuring linear displacements.

2. The Transformation of G.S.R. Measures

As just explained measures taken from the graphic records consist of 1. the base level in ohms before a stimulus, 2. the ohms decrease which constitutes the reflex. There are two common observations which suggest that these measures need transformation before they can be conveniently handled by statistical procedure. (Haggard (7) discusses the point.) First the distribution of the reflexes expressed as ohms change is commonly skewed rather than normal. Smaller responses are commoner than large ones. Second, over the range usually encountered the reflex is strongly correlated with the base level. (At higher base levels, such as appear when S is asleep, or nearly so, the relation does not hold (3).) For some purposes, as when one is interested in the total effect of the stimulus upon the individual, one might want to deal with an absolute measure of the response nevertheless. But where the purpose is to compare the effects of several stimuli upon an individual, the effect of his pre-existing state would be intrusive.

Various proposals have been made for transforming data to remove these undesirable features (2) (7) (8) (9). In most of these the method of arriving at a transformation has been by trial and error. A set of data is subjected to one transformation after another until one appears to get rid of the undesirable characteristics. Such a procedure does not give much assurance of generality: what works measurably well for one set of data may not do at all for another. J. Lacey's method of reducing each reflex by the regression of reflexes upon initial resistance seems to be a general method for eliminating the effect of resistance level, but does have the drawback of interfering with the independence of the resulting measures. For Darrow's method (using change in log conductance) there is an external criterion: the amount of sweat secreted by the glands. But whether this is a good criterion of sympathetic excitation is uncertain.

In the present state of knowledge it seems necessary to discover a satisfactory transformation for each set of data one has to deal with. In our principal experiment using the g.s.r. 59 S's were studied. Each had a series of eight questions dealing with taking money of various denominations. (For full details of the procedure see subsequent section of the report.) Galvanic skin responses were recorded by using two channels, one showing the responses on the right palm, the other on the left. All responses and base levels were measured and converted into resistance values as described. Since the correlation of response and base level seems to be the effect of greater importance first attention was given to it. Throwing together all responses for all S's two scatter diagrams were plotted, one for each g.s.r. location. As would be expected from reported results a strong positive relation was evident. To determine the nature of the regression the mean and standard deviation of the population in each column was computed (mean response for class interval of base resistance). These are shown graphically in Fig 2. Three conclusions are evident:

1. The standard deviations and means of the categories are nearly equal.
2. Both means and standard deviations are linear functions of the base level.
3. The regression lines come very near passing through the origin.

These facts provide a clear indication for a response measure which will be independent of base level. Ratios of response size to base level will be free of correlation with base level in both mean and standard deviation. The ratios therefore form the basis of further treatment of our experimental results.

It is hardly possible to maintain that this technique is generally applicable on the basis of this one set of results. If the results of a large number of experiments should show the same properties one would induce the generalization. Or it might be possible to show that a g.s.r. produced by the same amount of neural excitation is necessarily proportional to the apparent resistance by reason of the physical-chemical mechanism. Certain evidence of this sort appears in an early study (3). The apparent resistance is almost altogether in fact a counter-e.m.f. which is produced by the polarizing current. If the polarizing current is increased the counter e.m.f. increases, though less than proportionally. (Apparent resistance, $\frac{E}{I}$, therefore decreases.) By such means the polarization of the tissues is increased artificially. When this is done the size of the g.s.r. to a standard stimulus, in terms of apparent resistance change, is also less, showing approximate proportionality to the apparent resistance. Depolarization here seems to depend on the amount of polarization. It might reasonably be supposed that the relation would hold in naturally occurring states of polarization likewise.

The naturally occurring state of polarization is dependent in part anyway upon the mean level of antecedent excitation in the sympathetic system. So it may be that the effect of an increment in excitatory discharge upon the sweat glands is proportional to the amount of further depolarization which is possible, a function which has been suggested for other psychophysical relations. Verification of this hypothesis would provide a rationale for the treatment of g.s.r. data.

Putting g.s.r. measures into ratio form, however, does not guarantee normality of the resulting distribution. The sort of distribution found in the present data (Procedure 6) is shown in Fig. 3. Obviously it is non-normal.

FIG. 2 RELATION OF MEANS AND SD OF G.S.R. (IN OHMS) TO PRIOR RESISTANCE LEVEL.

Numbers at points indicate step-intervals of resistance used.

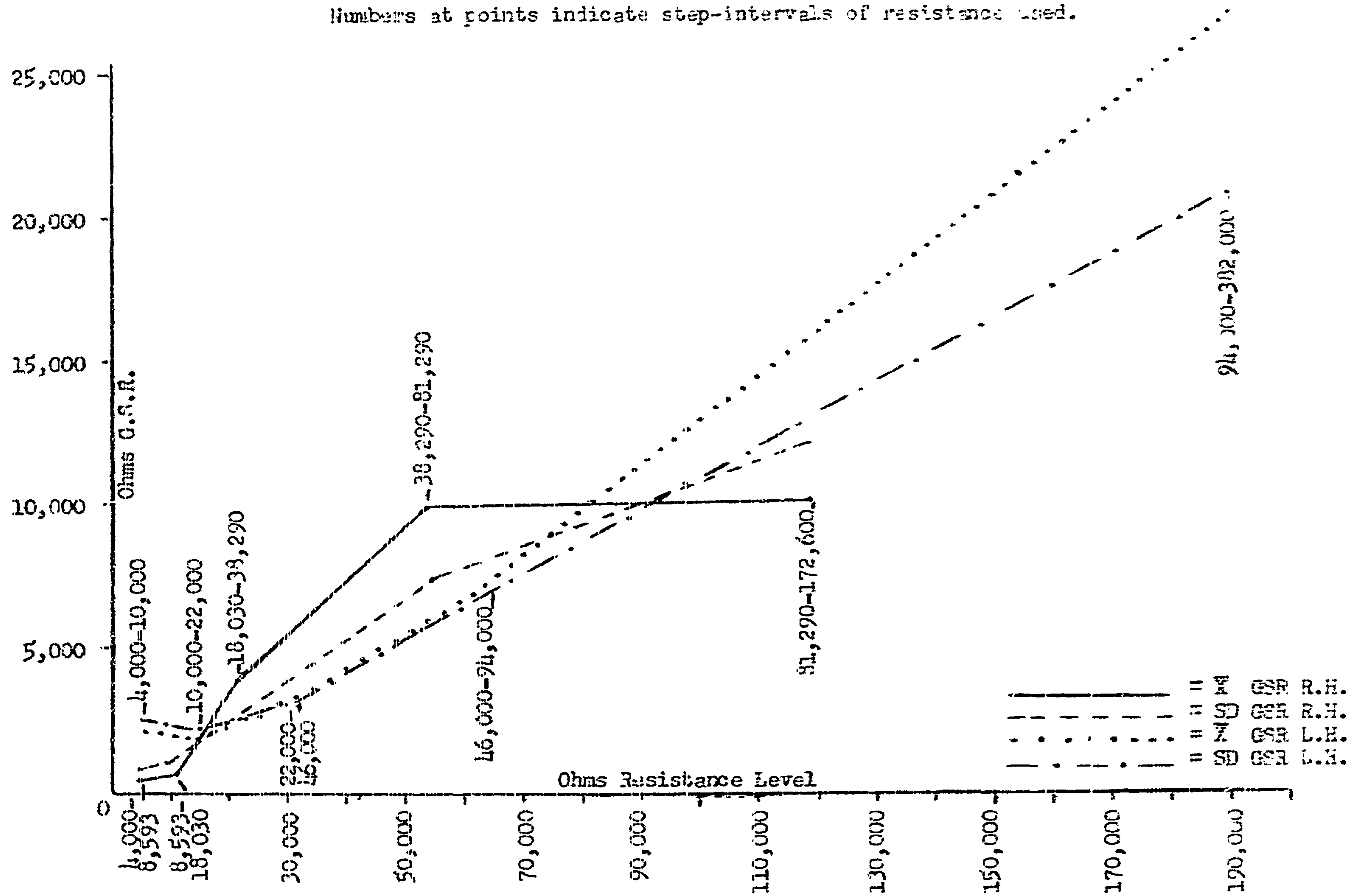
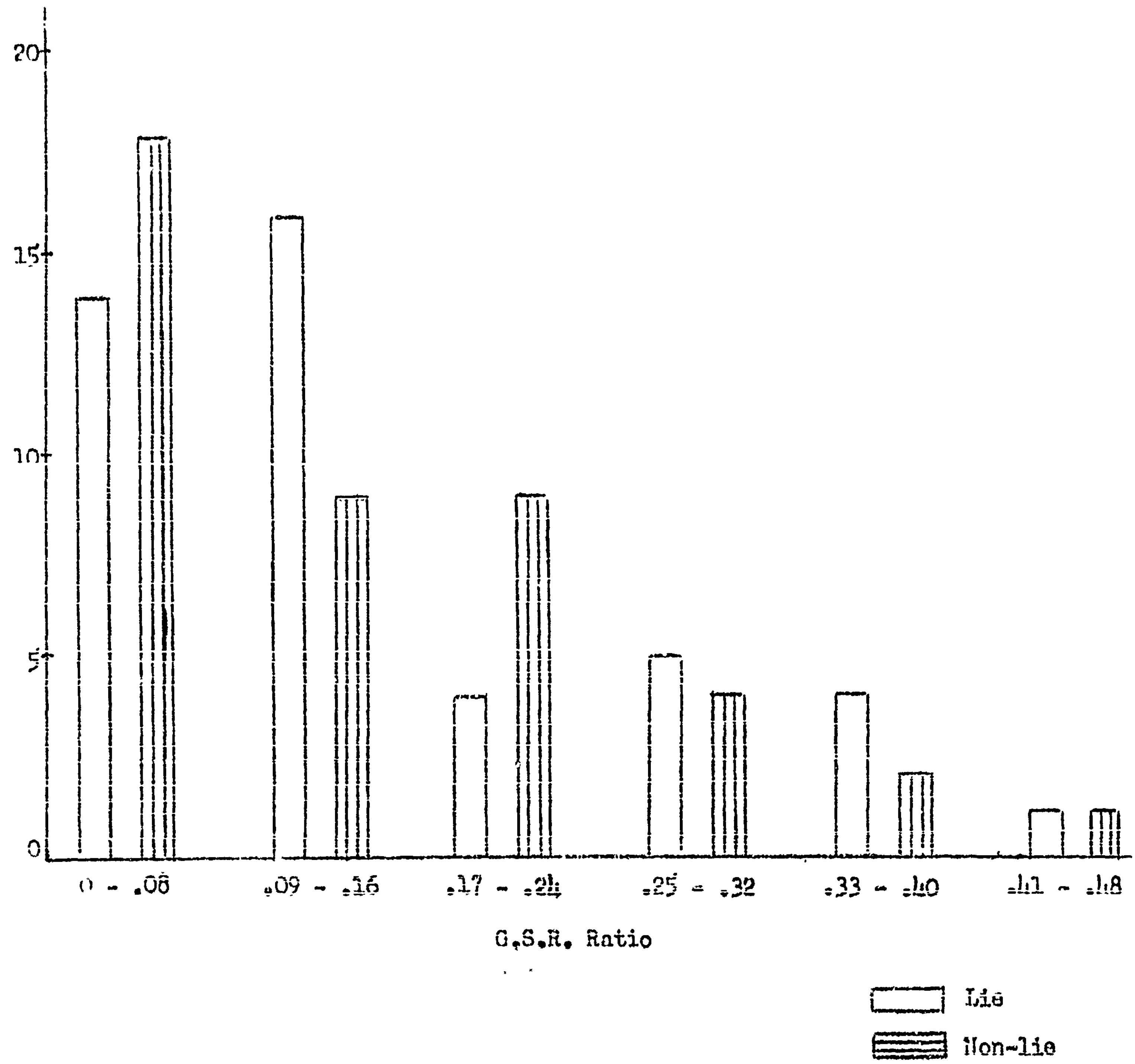


FIG. 3

FREQUENCY DISTRIBUTION OF G.S.R. (RIGHT HAND) ACCOMPANYING LYING AND NON-LYING. 44 CASES. MEAN OF 2 LIE AND 2 NON-LIE RESPONSES FOR EACH CASE.



It may be that the heavy accumulation of measures at the lower end derives from the fact that zero is an effectual lower limit of the measure. A relatively weak stimulus would fail to bring a good number of responses over the threshold. If this interpretation is correct (and it could be checked experimentally) then there is no one distribution form for g.s.r. data: the form would depend on the mean size of the response.

With a skewed distribution such as our data show it may be advisable to use a further transformation of the ratios simply for statistical convenience. In our analysis of variance of g.s.r. data a log transformation was used, since it seemed to provide a reasonable approximation to a normal distribution.

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CHAPTER XVI

AMPLIFIERS WITH AUTOMATIC RE-SET AND CONVERTER AMPLIFIERS

Many of the autonomically controlled processes which respond to stimulation are relatively slow changing. The galvanic skin response is fairly typical. A large response will take several seconds to reach its maximum and perhaps four or five times as long to recede again. With phenomena of this sort amplifiers of the usual type containing reactances are impractical because the reactances would need to be of such enormous size. For amplifying such changes one must resort to direct coupled amplifiers or to converting circuits in which the slow wave is made to modulate a carrier. The system used in the present studies was a combination of both. Direct coupled amplifiers were used as the chief means of increasing the slow signals. In each case then a convertor amplifier further magnified the signal before it was delivered to a power amplifier in the recording unit.

In direct coupled or converter amplification an increase or decrease in the direct current component of the input is likely to force the indicator off scale. Ordinarily a manual adjustment is required to bring it back to a useful range. There is often loss of a critical point in the record while this change is being made. Further, with multiple channel recording no operator could monitor all channels at once. For this reason a set of d.c. amplifiers which include automatic monitoring devices was constructed. These will automatically shift the recording range -- not the sensitivity -- whenever the signal passes the limit of the one on which it is operating. The circuit for one of these is shown in Fig. 1.

The signal which is introduced into a d.c. amplifier may be considered as made up of two components: a slow wave and a d.c. potential which does not change during the wave. It is commonly true that the d.c. component is greater than the wave. While one may wish to know the value of this d.c. component there is usually no need to amplify it. If it is large with respect to the wave it would, if amplified merely obscure the wave.

It is desirable therefore to get rid of this d.c. component. Since a condenser cannot be used for the purpose (its proportions would have to be outlandish) a bucking voltage must be introduced, a voltage which in our case is self-adjusting to the size of the d.c. component. This bucking voltage is provided by the series of 150 ohm resistors shown in the diagram, which are actually mounted on a motor driven rotary switch. The upper end of this series is connected to the high voltage supply through a pair of dropping resistors so that the total voltage available across them is in the neighborhood of a volt. Depending on the position of the wiping contact a certain fraction of this biases the cathode of first amplifier tube (12SH7). The fraction, of course, will be a certain number of tenths of the total available across the rotary switch.* How many tenths are in the circuit at a given moment is shown by an index which is attached to the shaft of the rotary switch. Numbers on this index show through a hole in the panel of the amplifier.

As shown in the diagram the input signal is impressed between the ground and the grid of the first amplifier (sometimes through resistors of the sensitivity control). The connection must be made so that the negative side of the d.c. input component is on the ground terminal. Then the signal

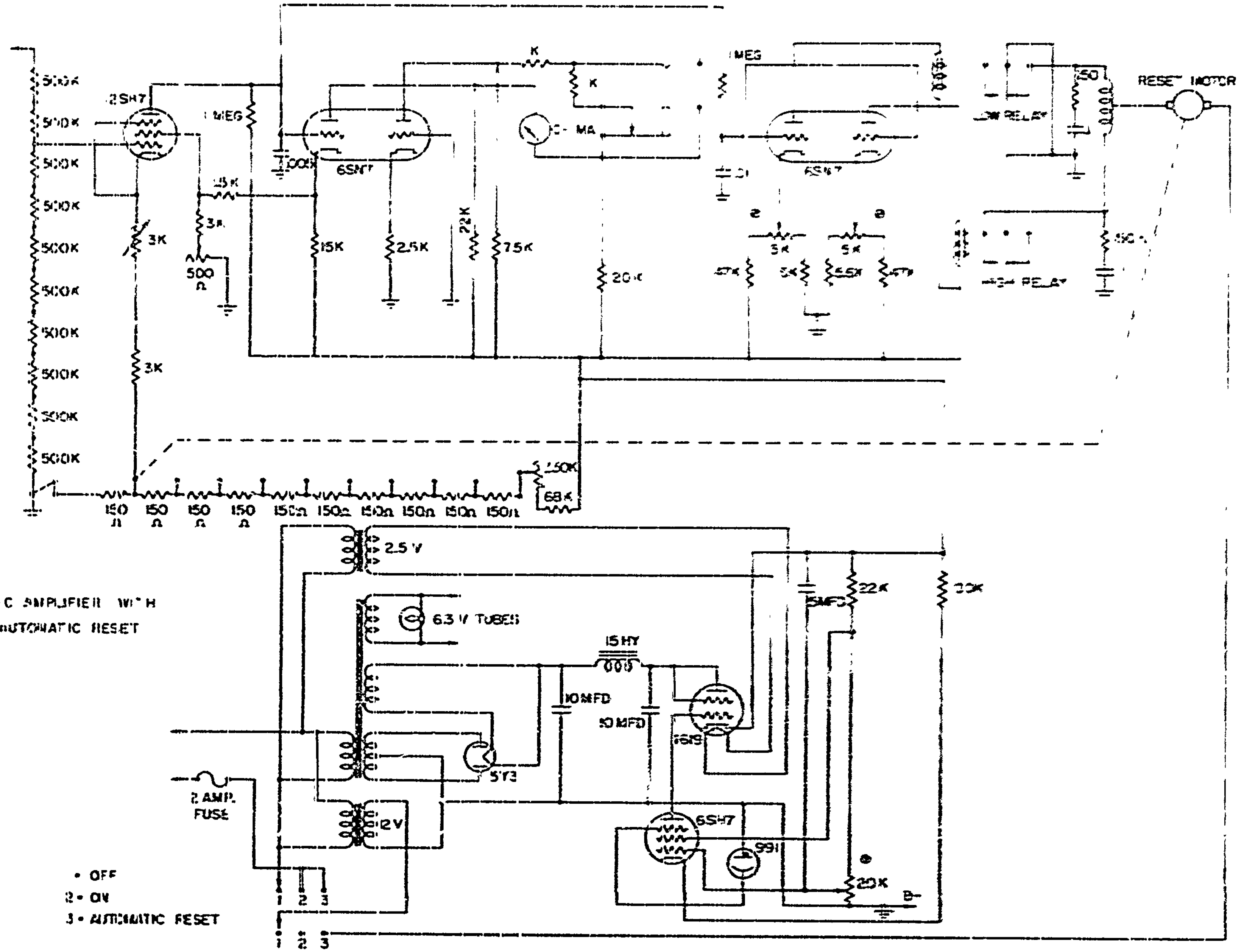

FIG. DC AMPLIFIER WITH AUTOMATIC RESET

and bucking voltage are in opposite directions in the grid-cathode circuit of the 12SH7, and the net grid-cathode voltage is the difference of the two, plus whatever is provided by the two 3K resistors shown in the cathode lead. When there is no input and no bucking voltage one of these (known as the "zero set") is adjusted so that the 12SH7 has its proper operating bias (with grid negative to cathode). When a signal is introduced the bucking voltage will be adjusted (by the device described below) until the tube has that amount of bias, or something near enough to it to be in its proper operating range. If a wave, positive or negative, appears in the signal the tube will transmit this. Should the wave exceed the operating range the re-set mechanism will be activated to introduce more or less bucking voltage.

The series of 500K resistors across the input serves as a sensitivity selector. These are mounted on a rotary switch which is manually operated. The sum of the 10 resistors is so large that no appreciable current is drawn by the device. According to the position of the switch a certain number of tenths of the whole signal is put into the amplifier. Of course the value of the whole can be obtained by appropriate multiplication.

The amplifier has two second stages, each composed of a 6SN7. The first of those serves to amplify the signal to provide the output of the system. The second amplifies the signal to provide the feedback required for the automatic re-set of the bucking voltage.

In the first of these stages the two halves of the 6SN7 are connected in quasi-push-pull fashion. If only one half were used it would be difficult to arrange for it to operate on a linear part of its characteristic. The other half therefore is used to oppose the one and improve the linearity. The output meter (0-1MA) and the external output connections are located between the two plates of this 6SN7. Only one of the grids, however, is connected to the signal, the other being grounded.

In the other 6SN7 the output of each half is used to operate a relay which in turn causes the re-set motor to run forward in the one case and backward in the other. The signal from the 12SH7 is given to both halves of this tube. When the instrument is originally set up the cathode bias on the first half is adjusted so that the tube conducts and throws its relay ("low" relay) whenever the output meter comes on scale from below. Since the relay is connected to break a circuit this means that the motor will run, in the appropriate direction, until there is an output reading on the meter, then it will drop out. The other half of the 6SN7 has a higher cathode bias and will not conduct enough to move its relay until the output meter reads full scale -- 1MA. It then throws the "high" relay which has a "make" connection and causes the motor to run in the other direction.

Since the motor turns the rotary switch which regulates voltage on the input grid this mechanism acts as step-wise negative feedback.

Two specially troublesome effects were encountered when these devices were first tried. With certain 12SH7 tubes there was a tendency for the grid to draw current even when it was negative, and when there is grid current the amplifier becomes non-linear. The remedy turned out to be proper adjustment of the screen voltage. A variable resistor for this purpose is shown in the diagram.

The rotary switch used in the re-set mechanism must be of the "shorting" type: it must have its wiper in contact with some terminal at all times, for otherwise the system will oscillate. Poor quality switches originally gave a good deal of trouble by frequently leaving an open contact.

When a d.c. amplifier was attached directly to S for g.s.r. recording and a high gain amplifier for EKG or EMG recording was also attached, it was necessary to use power supplied by batteries rather than the rectified power supply shown in the diagram. Otherwise the high gain amplifiers would pick up too much 60 cycle hum.

For experiments in which only one variable was recorded (one channel of g.s.r.) the output of one of these d.c. amplifiers was put into an Esterline-Angus recording milliammeter, 0-1MA sensitivity. For experiments requiring multiple recording further amplification was needed to drive the power amplifiers which moved the styli. It was also desirable that the signal should have a ground connection, which it does not as it comes out of the d.c. amplifiers. For these purposes converter amplifiers were introduced following the direct coupled amplifiers. The circuit for these is shown in Fig. 2. The signal is converted to a modulated 60 cycle wave by means of a vibrator* (without a ground connection). After two stages of amplification the signal is rectified and put into push-pull form with a center ground. This arrangement gives the type of input desired for the power amplifiers. It provides more gain than necessary, and the gain control is therefore set at a rather low value.

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* Ordinary vibrators adapted to these circuit requirements were found to get out of adjustment very easily. A "Brown" converter proved satisfactory.

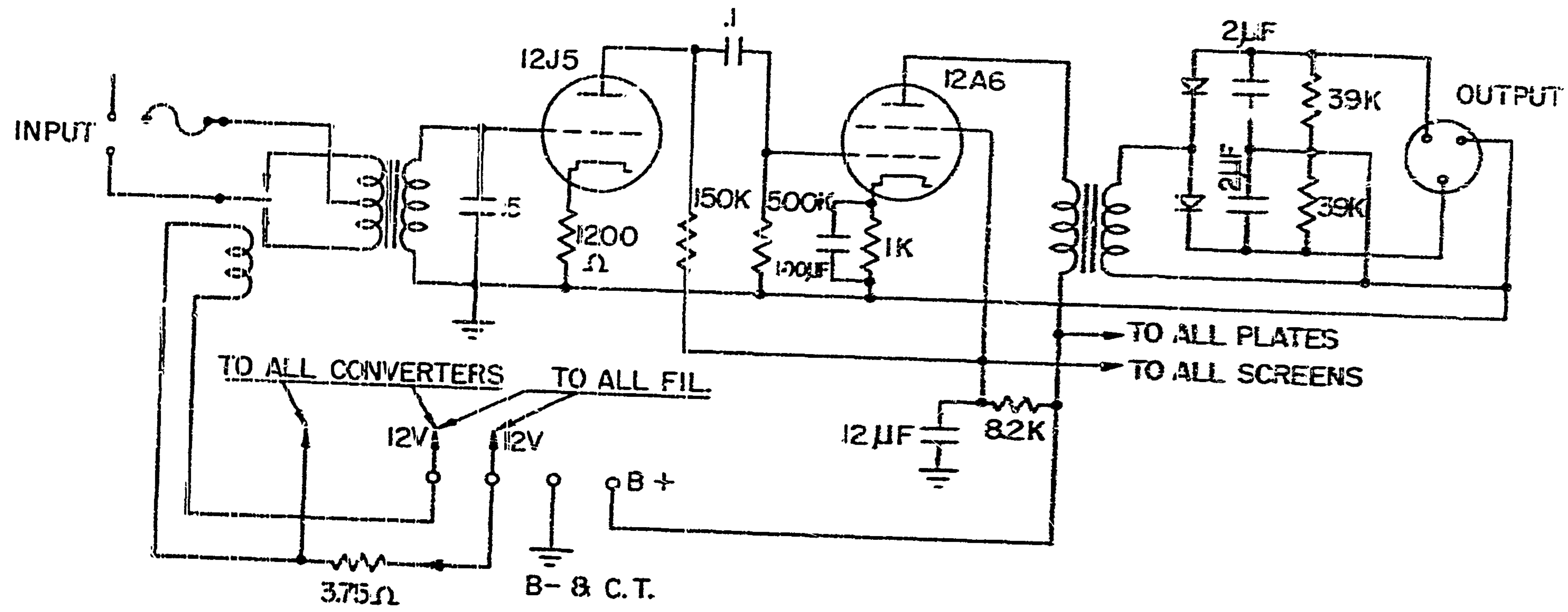


FIG. 2 CONVERTER AMPLIFIER

CHAPTER XVII

GENERAL RECORDING APPARATUS

For multiple recording the final units were the styli manufactured by Electro-Medical Laboratories. Two panels each containing six styli were mounted in horizontal position on movable "carts". In the carts were the power amplifiers and other circuits supplying the styli. To one side of each cart an Esterline-Angus chart drive was attached and coupled to the paper drive mechanism supplied with the Electro-Medical panels. The adjustable gear ratios of these allowed for varying the speed of the paper drive. By means of pulleys and a spring belt the chart drive also ran a take up spindle for the paper.

The styli write on Teledeltos paper (10 in. wide in our case) by passing a small current from the tip of each through the paper to the metal roller beneath. This current produces a chemical change in the coating of the paper. Voltage to supply these writing circuits was taken from the supply of the power amplifiers, through a dropping resistor so as to give about 150 v. on the styli.

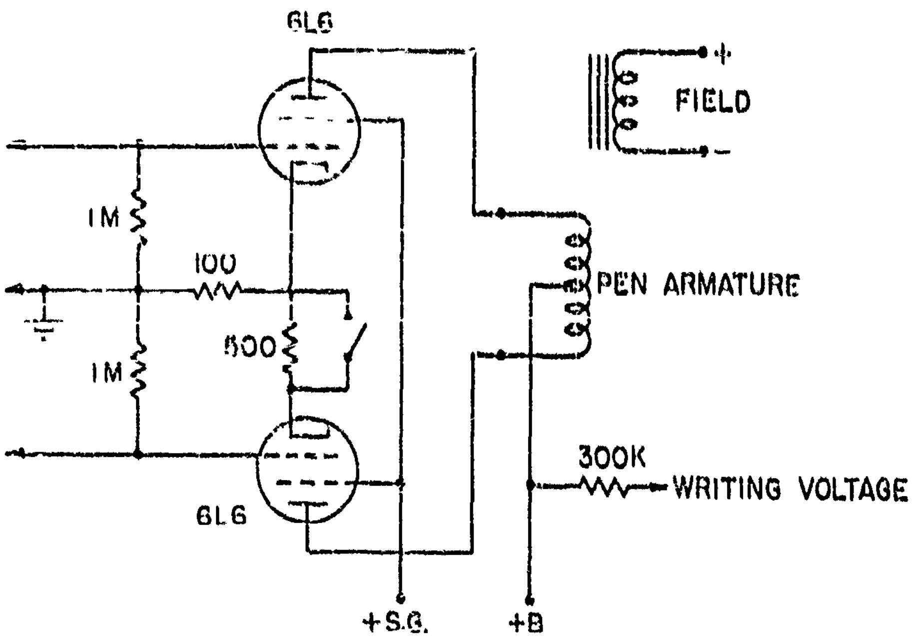
The movement of the styli is produced by an electromagnetic field and a pair of moving coils for each in push-pull arrangement. A pair of coil springs provides the restoring force. The field magnets were supplied first with the manufacturer's rated current by means of transformers and selenium rectifiers. Then in a rather fruitless attempt to improve the linearity of the deflections of the styli, the field strength was doubled on one set of units.

The moving coils of the instrument are designed to operate in the plate circuits of pairs of 6L6's working in push-pull. Fig. 1 shows the circuit used for this driving stage and the power supply for it. It is a simple direct coupled push-pull stage. When one of these channels was used to record the output of a d.c.-converter amplifier sequence the input signal was unidirectional. It was therefore advantageous to have the styli assume a zero position which was actually their maximum useful deflection in one direction. This was accomplished by using a differential bias on the two 6L6's in a given circuit. Then as the input signal increased from zero it would progressively overcome this differential bias and push the stylus through its center position, then produce an opposite bias and force the stylus to its maximum in the other direction.

When a stylus was used to record from an a.c. amplifier which would produce signals in both directions, equal bias was used on the 6L6's and the position of the stylus, in the absence of signal, was in the center.

An additional circuit was required ahead of the 6L6's for those channels used for recording integrated waves (Fig. 2). In the first place the output of the integrators after phase inversion is one-sided; it presents an output with one side grounded. The styli, and consequently the power amplifiers, are built for push-pull operation with a ground connection in the center of the input. Hence another phase inverter, the 6SN7 circuits in Fig. 2, converts the signal from one type to the other. This converted signal is then coupled through the 4 uf. condensers to the power stage.

RECORDING AMPLIFIER
(SIX IDENTICAL UNITS)



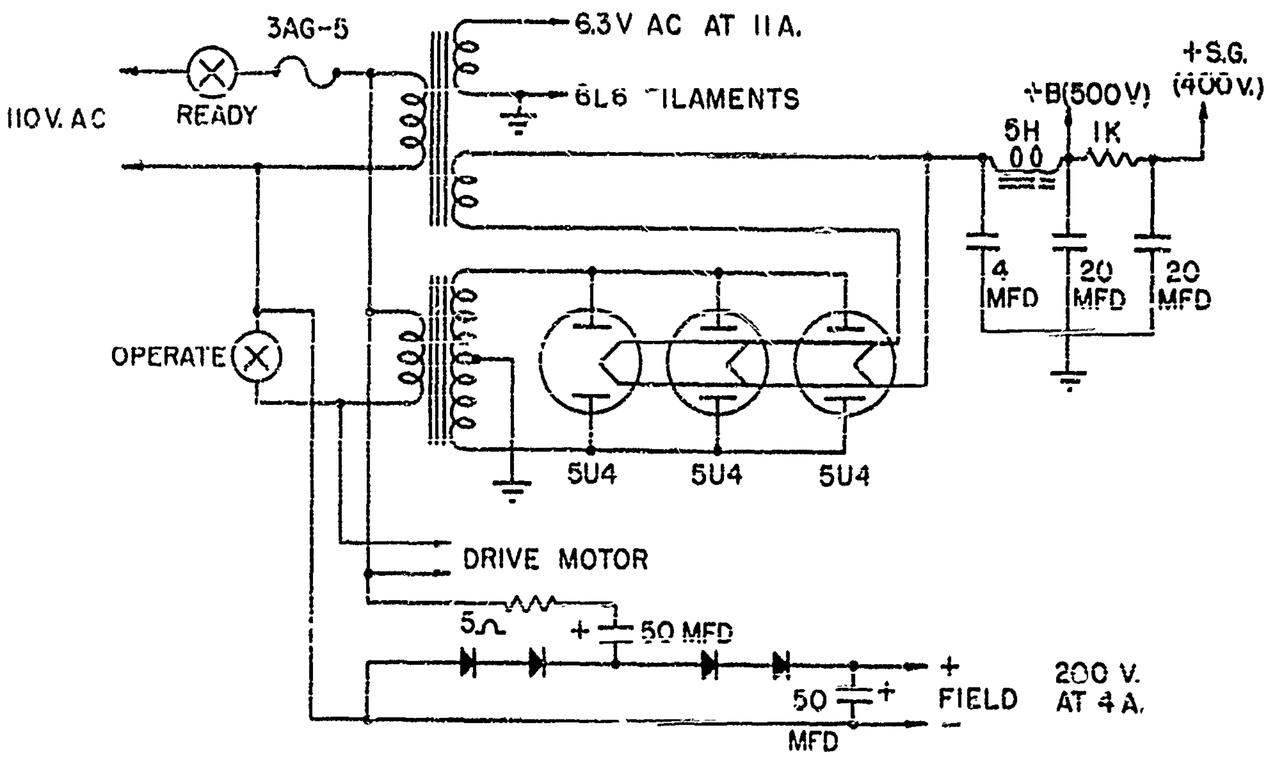


FIG. 1 RECORDING AMPLIFIER POWER SUPPLY

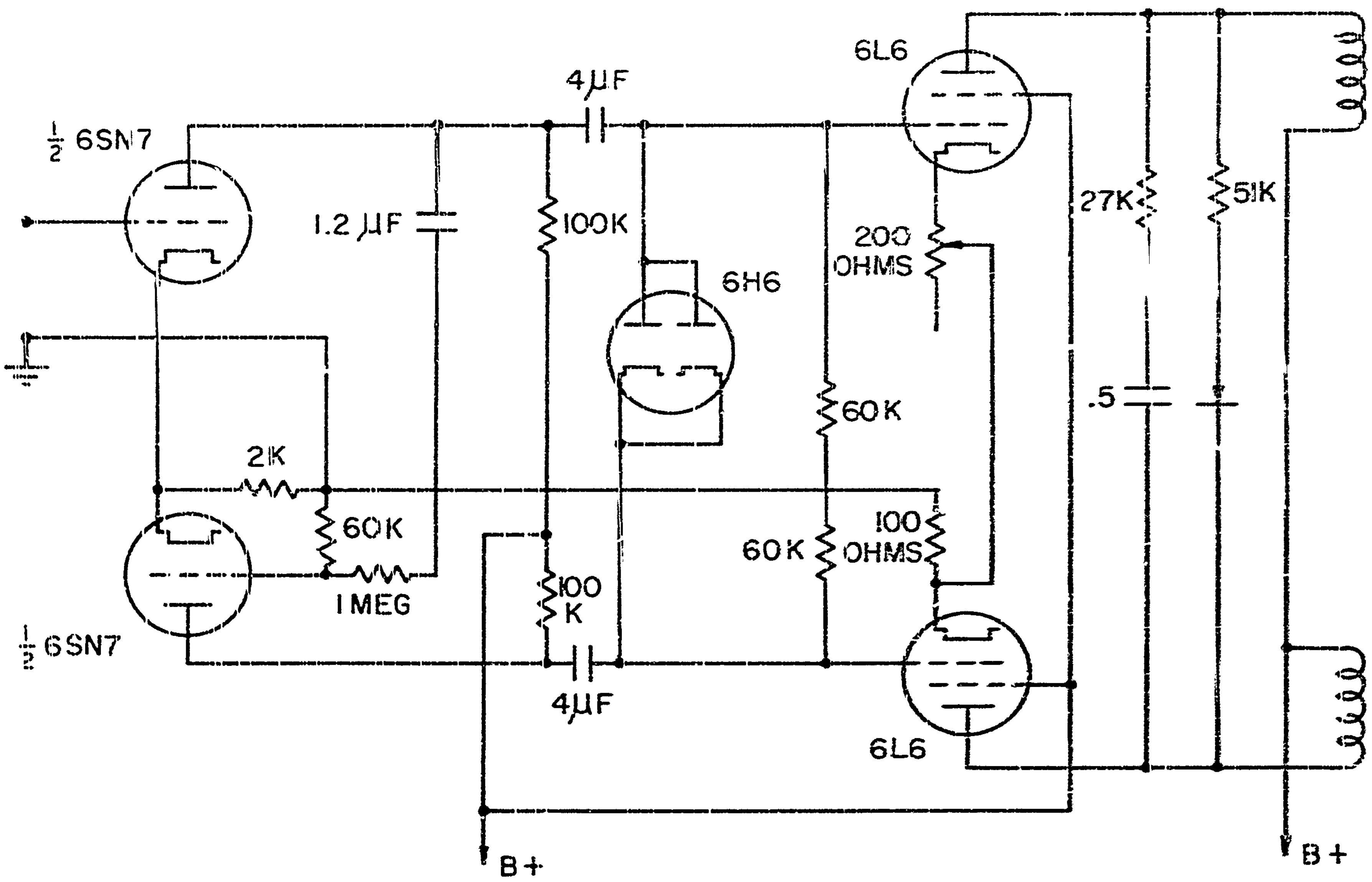


FIG. 2 PHASE INVERTER, RECTIFIER AND POWER AMPLIFIER CIRCUIT FOR INTEGRATOR CHANNELS.

When the integrated wave, being triangular, is passed through condensers there is considerable "back-swing" because the condensers take some time to return to their normal equilibrium. This has the effect of producing swings in both directions from the base line. Since bi-directional swings would make records more difficult to measure the 6H6 tube is inserted into the circuit to eliminate the "back-swings". This rectifier will have no effect on the output of the preceding condensers so long as it is in the desired direction. When the direction is reversed, however, the tube becomes conductive and allows the condensers to discharge very quickly. Thus a signal is maintained which is always in the same direction from ground in a particular part of the circuit.

The electrical circuits supplying the signal voltages to the moving coils of the styli proved to respond linearly with respect to input size over the operating range of the coils. Although the manufacturer reports that the styli are capable of about a $1\frac{1}{2}$" deflection overall, it was found that their range of linearity is much less than that. In fact it is about 3/8 of an inch for d.c. signals. This limitation is evidently in the springs which return the stylus to position, and against which the signal must work. As one spring is stretched during a deflection the other shortens. The pull exerted by the two is equal in the middle position, but as the stylus is deflected the pull of the shortened one becomes less and less and that of its opponent greater and greater. Consequently more and more force is required to deflect the stylus a given distance.

A partial solution to the problem was secured by doubling the length of the writing levers. The longer levers were constructed of light aluminum sheet tapered from 3/16" to 1/8" to keep the mass and momentum as low as possible. A steel phonograph needle was fitted into the tip to serve as a marking point. (The needle is changed frequently because of wear.) With this arrangement there is a linear deflection of the stylus of 3/4" (3/8" in each direction from center). Though there was no question but that these longer styli would record such slow changes as breathing, g.s.r., etc., it was necessary to test their response to such signals as those from the action potential integrators. They proved even there, however, to follow the signal about as well as the shorter levers. So long as deflections were kept small, therefore, they could be treated as linear. This limitation made for considerable waste of space which could have been used for greater accuracy or convenience in reading, but recording was possible. Inadvertently exceeding the limit of linearity certainly caused the most serious errors in the data collected. In the case of g.s.r. records the limit was intentionally exceeded and the data interpreted by means of a non-linear calibration curve.

In order not to preoccupy one of the regular recording channels for time and signal indications a special type of marker was used in the later experiments for these purposes. This was a short lever which would make a small upward movement in response to one relay magnet, a larger movement in response to another and a downward movement in response to another. Two of these deflections were used as stimulus signals and the other as a time signal. To produce time marks a small synchronous motor drove a cam which would make and break a circuit each second or half second as desired.

Since the styli write by means of "electric ink" it is possible to produce a signal by a brief interruption of this flow. This device was used to signal the beginning of the application of pressure to the blood pressure cuff by the mercury pump. At the beginning of each cycle there was a brief interruption of the writing voltage on the pulse line, an interruption which was produced by having the pump cam break the contact of a micro-switch.

CHAPTER XVIII

PROCEDURE FOR MAJOR EXPERIMENTS

The preceding chapters of Part II have included a discussion of the physiological and psychological background which has influenced the preliminary choice of variables to be examined in this research, and also describes the apparatus and techniques of measurement used to record those variables. Further selection of variables was based on preliminary experiments, some of which are described in Part I. The present chapter and succeeding ones are concerned with two major experiments in which the subjects committed a laboratory crime, following which they were questioned, and a number of responses were recorded simultaneously. Variables representing various aspects of these responses were analyzed singly and, by means of a procedure which we have called pattern analysis, in combination. The results of the first of these experiments, the procedure for which will be indicated subsequently as Procedure 6, were also examined by means of pattern analysis to determine weightings of each variable for the prediction of deception. The second experiment is essentially a repetition of the first using a new group of subjects in order to validate the obtained weights. The questions used in the first experiment were repeated three times in order to increase reliability.

Eighty-nine subjects were run in the first experiment. Of these 31 subjects were discarded before data were analyzed. These subjects were eliminated because with a fixed order of questions the critical questions concerning the "crime" they committed came first and second in the series. Because of the adaptation of many responses which was found to occur (in preliminary experiments) it seems desirable to reduce variability by eliminating subjects who lied on these first two questions. The analysis of single variables was based on the remaining 58 subjects. The pattern analysis was based on the 44 of these 58 subjects for whom acceptable data was obtained on all variables.

In the second experiment 29 subjects were run. Seven were discarded because the "crime" they committed was mentioned in the first two critical questions. An additional three subjects were omitted from the pattern analysis because of incomplete records. The procedure for this second experiment is hereafter called Procedure 7.

Procedure 6*

Each subject was told that he was about to take part in a lie detection experiment. He was shown four sets of coins: ten nickels, five dimes, two quarters, and a fifty cent piece. A cover was placed over the coins and the subject was instructed as follows:

> After I leave the room, I want you to take one of the sets of coins and put it in your pocket (or purse); then replace the cover over the remaining coins. When I return, do not tell me which coins you have taken. Later on I shall try to find out by asking you questions about the coins. If I am not successful, you may keep the coins you have taken!

* Procedures 1-5 were successive modifications of procedures abandoned for various reasons before the final Procedures 6 and 7 were stabilized.

The experimenter left the room and returned after waiting long enough for the subject to remove and dispose of the coins. The subject was then seated at a table and the apparatus was connected for measuring the following responses: the right and left hand palmar g.s.r., the pressure pulse from the right radial artery, and the volume pulse from the left forefinger.

The subject was then informed that soon he would be asked to read aloud, but that before he did any reading, he was to sit quietly and relax. He was told that he would be notified when to begin reading. The reading matter was a page from a textbook in child psychology. The book was held in position at eye level by a clamp and stand which were located on the table in front of the subject. When the subject indicated that he understood the instructions, a pair of ear phones were placed on the subject's head and a microphone was positioned on the table close to his mouth. The microphone and ear phones were connected to a modified tape-recorder, which was wired so that the words spoken by the subject into the microphone returned through the ear phones after a delay of approximately .2 seconds. The typical effect of this "delayed feed-back" on naive subjects is to disrupt their speech noticeably. It was used in the present study to produce a mild emotional or stress situation.

While the subject was relaxing before the signal to begin reading aloud, a one minute record of his rest level responses was made. Immediately following this, the subject was asked to begin reading. The subject read for one minute and a record was made of his responses during this reading period. The feed-back equipment was then removed and apparatus was connected for measuring the following additional responses: thoracic breathing by means of a mechanical-electric pneumograph, and mouth and nose breathing by means of a thermocouple.

The subject was next informed that the experimenter was going to leave the room and that he would communicate with the subject by means of the loud speaker and microphone which were located on the wall in front of the table. The subject was told that he would be asked a series of questions which he was to answer aloud. Most of the questions, the subject was told, would have to do with the coins. He was instructed to tell the truth in answering all of the questions except those questions that had to do with the particular coins that he had taken; he was told to lie about the coins he had removed. He was reminded that he would be permitted to keep the coins that he had taken if the experimenter was unable to discover from his questioning which coins had been taken. After the experimenter was certain that the instructions were understood he left the subject's chamber.

After about a one minute delay the recorder was turned on and a series of 14 questions was asked. The questions were asked at a rate of about one question every minute. The questions were always asked immediately after the break in the pulse pressure line which indicated that the mercury pressure on the arm was beginning to increase. The first four questions were "neutral" questions; the next eight questions were concerned with the coins; and the last two questions were used to produce a mild stress situation. The questions that were asked were:

1. Can you hear me?
2. Is today Sunday?
3. Did the light just go off?
4. Are you comfortable?

5. Did you take the nickels?
6. Did you take the fifty cent piece?
7. Are the quarters still under the box?
8. Did you take the dimes?
9. Are the nickels still under the box?
10. Are the dimes still under the box?
11. Did you take the quarters?
12. Is the fifty cent piece still under the box?
13. Do you feel an electric shock on your left hand?
14. Don't move your left hand! We seem to have a bad connection and we don't want you to get shocked!

About one minute after the last question the recorder was turned off and the subject was removed from the apparatus. He was reassured about the shock threat situation and asked not to communicate with other potential subjects about the experimental procedure.

Procedure 7

The subjects in this experiment were 29 undergraduate men and women, some of whom had served previously in psychological experiments. The procedure of this experiment was intentionally almost identical with Procedure 6. The present study differed from Procedure 6 in the following respects:

1. No responses were recorded until after the reading with feed-back.

2. Questions #13 and 14, which were concerned with the shock, were omitted.

3. The following additional questions were asked, tripling the number of questions concerned with coins in order to increase reliability.

    13. Did you take the dimes?
    14. Are the quarters still under the box?
    15. Are the nickels still under the box?
    16. Did you take the fifty cent piece?
    17. Did you take the quarters?
    18. Is the fifty cent piece still under the box?
    19. Did you take the nickels?
    20. Are the dimes still under the box?
    21. Did you take the quarters?
    22. Are the nickels still under the box?
    23. Did you take the dimes?
    24. Are the quarters still under the box?
    25. Is the fifty cent piece still under the box?
    26. Are the dimes still under the box?
    27. Did you take the fifty cent piece?
    28. Did you take the nickels?

A rest period was introduced between questions #16 and 17 which lasted approximately five minutes. The pressure cuff was loosened and the subject was allowed to move about if he so desired.

CHAPTER XIX

MEASUREMENT OF RECORDS AND ANALYSIS OF SINGLE VARIABLES

(Procedure 6 and 7)

In these experiments six recording channels were used (plus the auxiliary marker for indicating time and stimulus. A section of the record is shown in Fig. 1. The two upper lines in the figure are g.s.r. records from the right and left hands respectively. Both electrodes, in each case were placed on the palmar surface of the hand. The third line from the top is the record from the mechanical-electric pneumograph; the fourth is the breathing record taken from the thermocouple in front of S's nose and mouth. The fifth line is a record of the pressure pulse taken from the right radial artery and used for the measurement of various blood pressure values as explained below. The breaks seen in the line are the signals which indicate that the mercury pump was beginning to apply pressure. The pressure release came, as apparent, a little more than half way between the breaks. The sixth line is a record of the volume pulse taken from the left forefinger.

For each response used as a part of the study the following measurements were taken in Procedure 6:

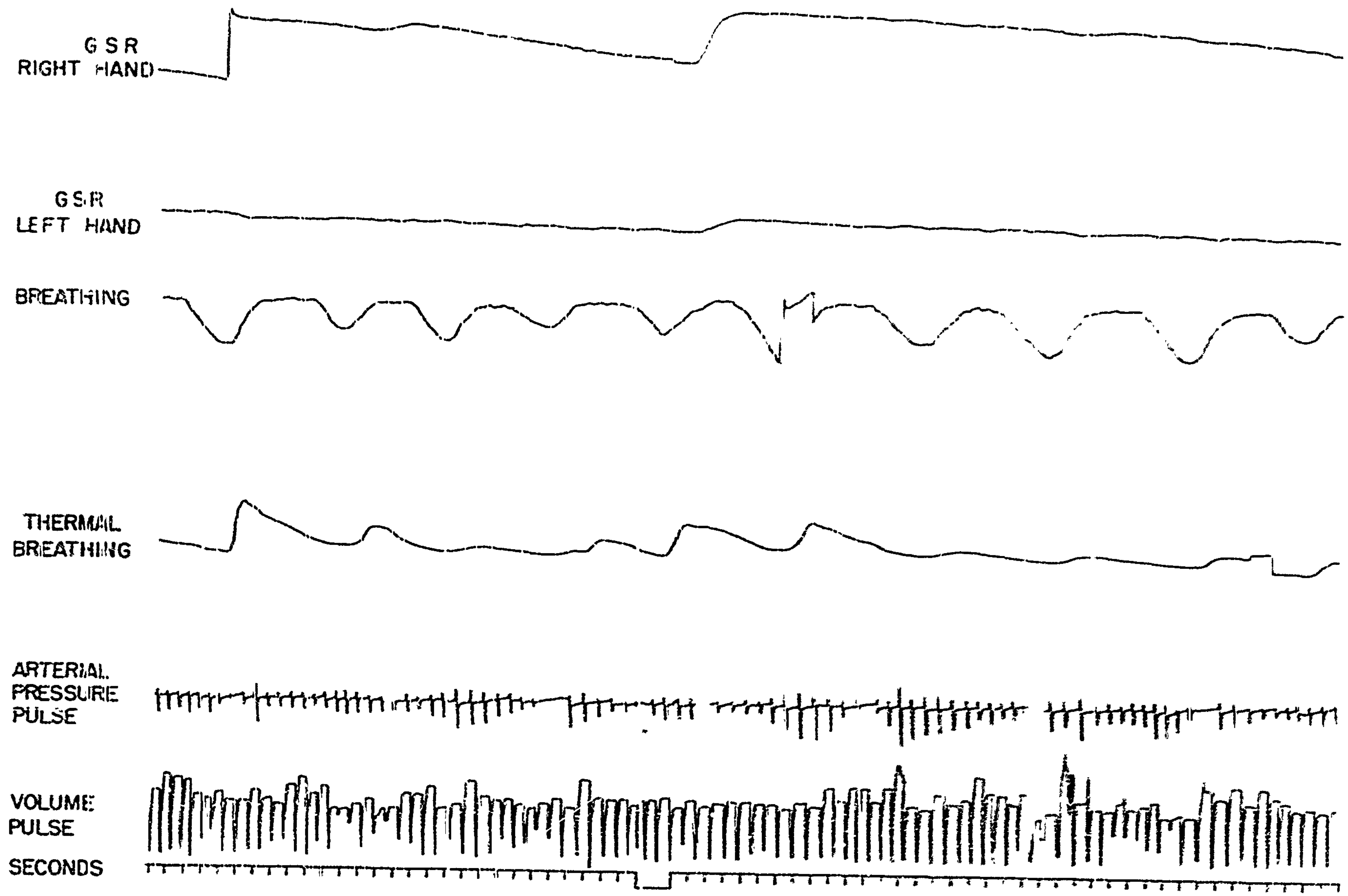
1 and 2. G.S.R. right and left hand. Before each stimulus the level of skin resistance shown on the g.s.r. lines was measured and calculated as described in the section on g.s.r. recording.

The highest point reached by the g.s.r. lines in point following the stimulus was measured and converted into ohms change from the preceding level. In most cases it was necessary to use a non-linear calibration table to make this conversion. The ohms change in each case was then converted into a fraction of the prior resistance level in accord with the reasoning given in the section on g.s.r. recording.

3 and 4. G.S.R. Time, right and left hand. The time between the stimulus and the g.s.r. maximum was measured in each case. Because one cannot definitely locate the stimulus when it is an oral question a measurement of latency was impractical. The time to maximum, being longer, is less disturbed by this uncertainty.

5. Breathing Amplitude. As shown in Fig. 2 both breathing records wo divided into standard periods for measurement. The first (A-period) covered two inches prior to the stimulus. (Two inches equals ten seconds here.) The half inch following the stimulus was not measured, on the assumption that S's reply might affect breathing there. The two inches following this was marked for measurement (the C-period). These periods were selected merely on the basis of record inspection which suggested that variations might be found in them. Each of the two-inch periods was further divided into halves, designated A1, A2, etc. In each of these the highest point and the lowest point of the breathing curve was located and the difference measured. These measures provided our readings of breathing amplitude.

6. Breathing Rate. Breathing frequency was measured by counting the number of half cycles of the breathing curve in each of the above periods. Smaller fractions were rounded to the nearest half.


G S R
RIGHT HAND
G S R
LEFT HAND
BREATHING
THERMAL
BREATHING
ARTERIAL
PRESSURE
PULSE
VOLUME
PULSE
SECONDS

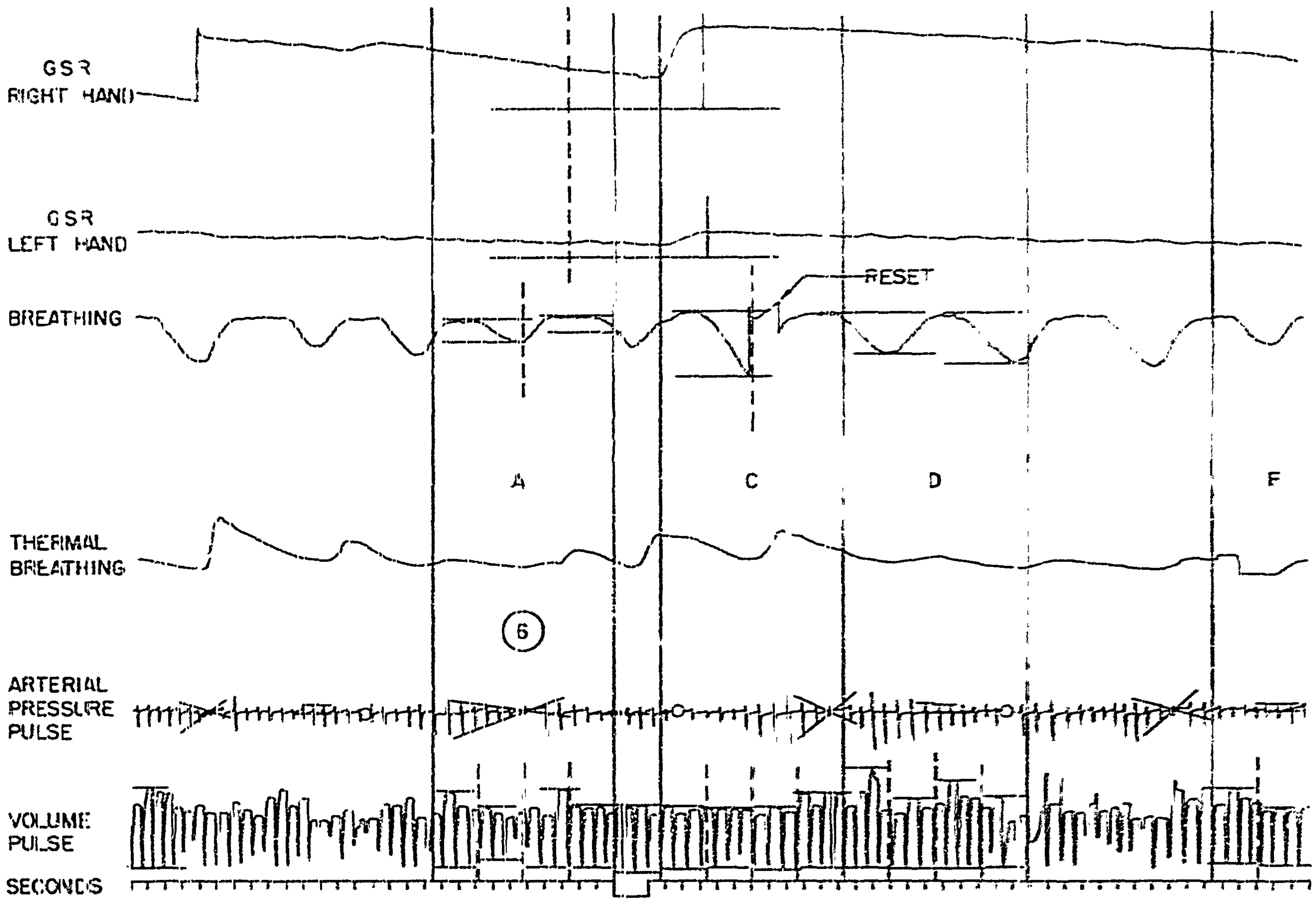


FIG. 2 SECTION OF SIX CHANNEL RECORD MARKED FOR READING

6a. Breathing Time. At a later time records were re-measured in a different fashion, so as to avoid this approximation. According to the new plan measurements were made of the time occupied by three breathing cycles prior to the stimulus. Half an inch after the stimulus was omitted and the time for each of two groups of three cycles thereafter was measured.

7. Thermal Breathing. Similar periods were marked off for the thermal breathing record. In those the maximum and minimum points were measured, the edge of the paper being the reference line. These measurements were not subtracted, but entered separately into the tables.

8. Systolic Pressure. On the pressure pulse line the distance between the onset of applied pressure and the disappearance of the pulse was measured. To determine the point of disappearance an extrapolation was made from the peaks of the last two (diminishing) pulses to the base line. This measure was taken to represent systolic pressure. (Where the pressure cuffs have been too loosely applied to the arm the pulse would not completely disappear. Some records had to be discarded for this reason; some could still be measured by the extrapolation device.) As the resulting measure was presumably proportional to the height of the mercury column, it was left without conversion. One pressure cycle just before the stimulus and the three immediately following were measured in this manner. It was believed that relative measurements of the pressure would be less subject to technical errors. The systolic measures after each stimulus were therefore expressed as ratios to the measure taken before each stimulus.

9. Diastolic Pressure. The size of the pulse on this line typically shows an increase just before its final decrease. The distance of this maximum from the onset of applied pressure was measured. According to the reasoning given in the section on cardiovascular techniques this should indicate diastolic pressure. So far as possible a diastolic measurement was taken to correspond to each systolic and the readings were put into similar ratio form.

10. Pressure Pulse. The amplitude of the pressure pulse was measured during a part of the pump cycle when no pressure was being applied. The amplitudes of three pulses half an inch prior to the signal break were measured and averaged. These measurements were likewise taken for one pump cycle prior to each stimulus and three cycles thereafter.

11. Pulse Rate. The pulse rate and time per pulse cycle were read from either the pressure or volume pulse record, whichever was more convenient. The first measurement made was of frequency. The two inch blocks described for breathing measurement were used, and the number of pulses in each were counted.

12. Pulse Time. Since Operation 10 seemed to give rather irregular results the records were re-read in a different manner. Five pulses just before the stimulus were counted off and the distance covered by them was measured in millimeters. Similarly the time occupied by each of 3 groups of 5 pulses after the stimulus was measured. (On these records 1 second = 4.5 mm.)

13. Pulse Volume. For measurement of the amplitude of pulse volume the division into 2-in. blocks was again used. Two additional blocks were also measured. The two-inch block following the C-period was designated the

D-period. The next two inches were omitted and the following two, the F-period, were then measured. In this case there was a further sub-division into blocks half an inch long, designated A1, A2, A3, A4, C1, etc. The difference between the highest point reached by the pulse line and the lowest in each of these periods was the measurement used.

In summary we have the following variables and measurements of each variable.

Variable	Measurements
1. GSR I-RH	Base Level and Response
2. GSR II-LH	Base Level and Response
3. GSR Time RH	One measure per stimulus
4. GSR Time LH	One measure per stimulus
5. Breathing Amplitude	8 measures per stimulus
6. Breathing Rate	4 measures per stimulus
6a. Breathing Time	3 measures per stimulus
7. Thermal Breathing	8 measures per stimulus
8. Systolic Pressure	4 measures per stimulus
9. Diastolic Pressure	4 measures per stimulus
10. Pressure Pulse	4 means per stimulus
11. Pulse Rate	4 measures per stimulus
12. Pulse Time	4 measures per stimulus
13. Pulse Volume	12 measures per stimulus

There are therefore altogether 61 readings for each stimulus studied.

In Procedure 6 only those S's were studied who took dimes or quarters during the experiment. Those who took the other two denominations were excluded because the critical questions for them came first and last in the series of questions about money, and because such S's were relatively few. The responses measured for Procedure 6 were those to Question 1, a neutral question, and to Questions 5-14, which were those dealing with taking money (5-12) and the two shock threats (13 and 14).

In Procedure 7 fewer measurements were made, on the basis of the examination of Procedure 6 results. Omitted were the two g.s.r. times, breathing rate, thermobreathing, diastolic pressure and pulse rate. Further, only those questions were measured which concerned dimes and quarters during the money question series. The Question 1 response was measured, but responses to shock threats were not.

In handling the data for Procedure 6 the purpose was to find what variables and what measurements of each would discriminate between lie reactions and non-lie reactions when they were considered one at a time. In making this decision the first question was whether there was any response at all, on the average in a particular variable. The second question was whether there were differences in the responses in size or direction, depending on the nature of the situation, especially the lying, and non-lying situations. Where differences appeared it was necessary to decide which particular measurements of a variable would show them most. Finally it was necessary to discover whether there were any series position effects in the responses which would need to be allowed for in discriminating lying and non-lying.

At this point tests of significance for the several variables were not available. The variables were therefore judged according to the size of the mean differences and a non-quantitative estimate of their consistency in the sub-means for separate questions. A wrong choice here, based on misinterpretation of random errors would result in a lowered predictive value for whatever combination of measures was chosen when it was applied to the "shock" group (Procedure 7). Actually when the data for Procedure 7 were computed the mean trends were found to be about the same as those for Procedure 6.

Mean Trends

Since the results for the two procedures are much the same for mean trends the data from the two will be presented together though only the Procedure 6 data was available at the time the original analysis and selection was made.

1 and 2. G.S.R. There is a surprising lack of correlation between resistance levels and between responses for the right- and left-hand g.s.r.'s. For pre-stimulus resistance level the correlations for the two groups (Procedure 6 and 7) were .43 and .47. For responses they are .53 and .55. (In computing these correlations all resistance readings for each S for lie and non-lie responses were averaged together for each variable. Similarly responses were averaged, the scores being in ratio form.) Evidently the two channels of g.s.r. will yield rather different information.

There is a mean galvanic skin response, of course, to each question. Mean responses for lying and non-lying situations and for the shock threats are shown in Fig. 3. The lie response is greater than the non-lie. The shock threat response is intermediate, but the response is doubtless weakened by the position of the stimuli at the end of the series. The graphs include data from all non-lie as well as lie and shock threat questions. Later t-tests were made in which lie and non-lie responses to 10¢ and 25¢ questions were compared. The t-values are, for Procedure 6, GSR I, 1.44, GSR II, 2.37. (All t-values for Procedure 6 are from comparison of 2 lie and 2 non-lie responses for 44 S's.) On the basis of the data Procedure 6 both g.s.r.'s were included in the studies of combinations of measures. It is evident that the left palmar surface gives better responses for the purpose than the right.

3 and 4. G.S.R. Time. Fig. 4 shows the mean g.s.r. times for the three situations. The response to shock threat, it may be seen, occupies a larger time than the responses to the other two, which are relatively similar.

The time measures vary in the same direction as the amplitude measures for the g.s.r. Evidently there is a general tendency for the shape of the g.s.r. response to remain the same: when it increases in the one dimension it increases in the other. Though the correlation is not perfect it seems that the time measure would give the same information on lying and non-lying as the amplitude measure though rather less precisely. Accordingly the measures were not included in the combinations studied.

5. Breathing Amplitude. The mean breathing amplitude before and after the various types of stimuli is shown in Fig. 5. The breathing change

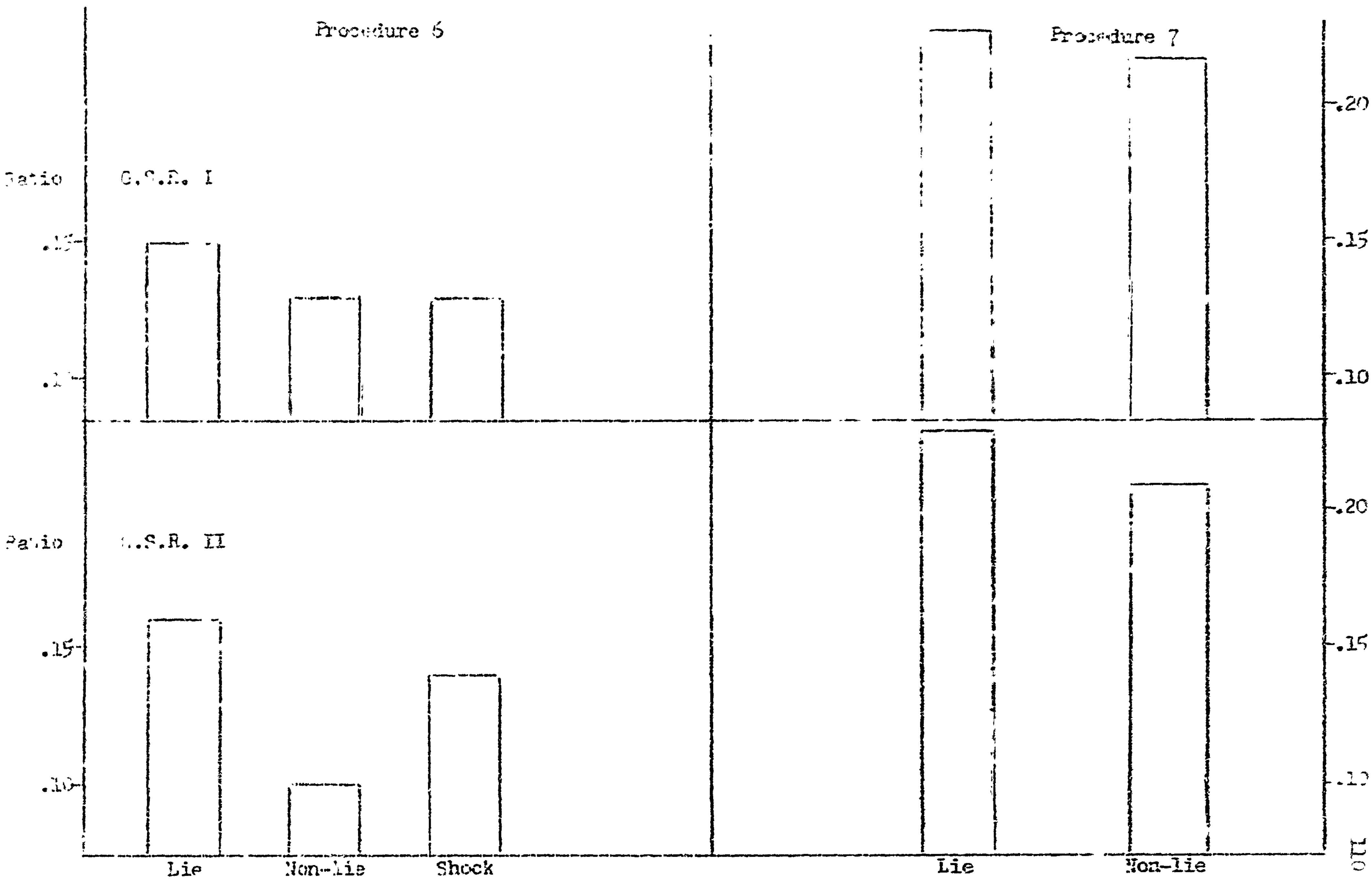


FIG. 3 MEAN G.S.R. AMPLITUDE (RATIO FORM)

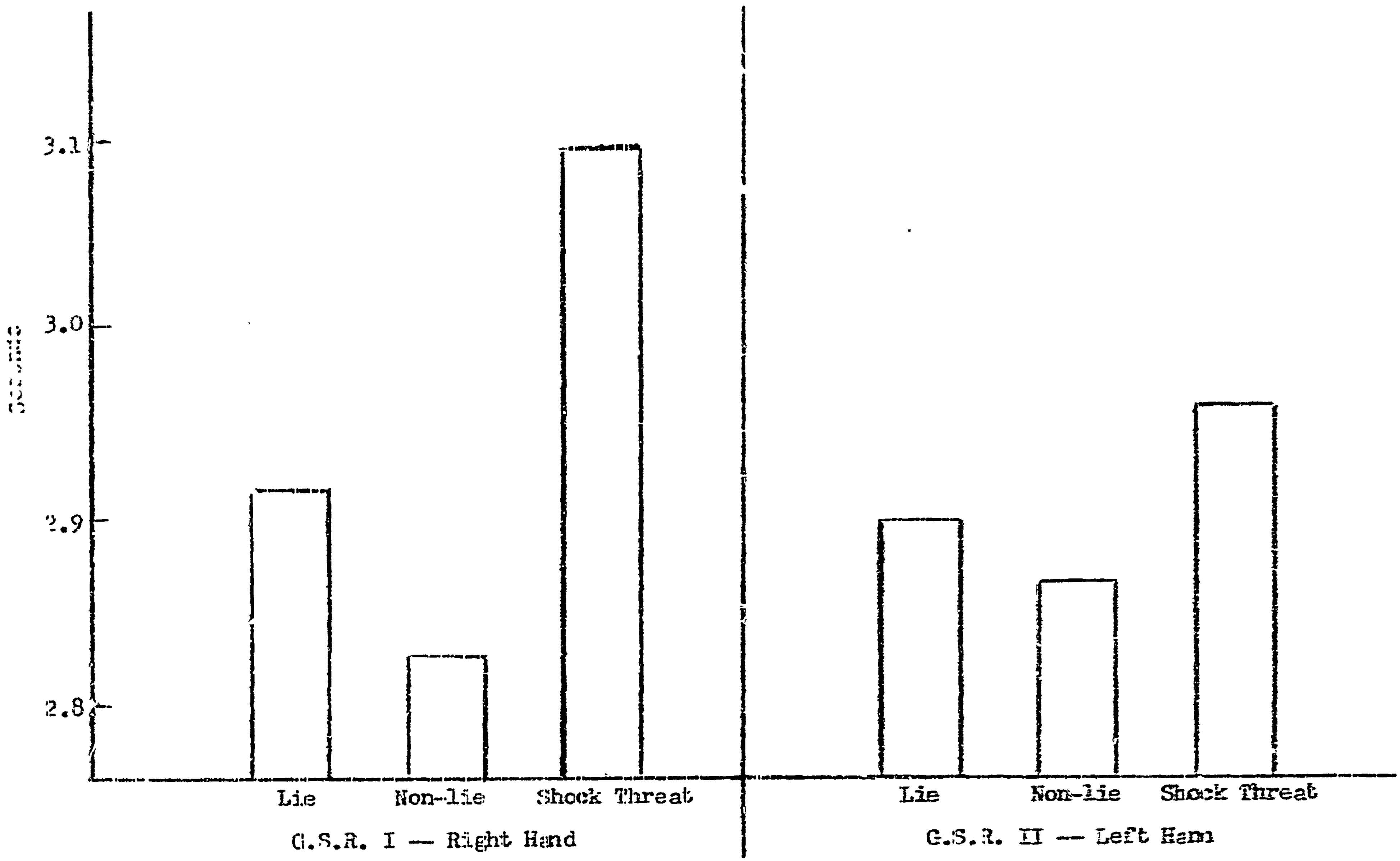


FIG. 4 MEAN G.S.R. TIME (PROCEDURE 6)
TIME FROM STIMULUS TO PEAK OF G.S.R.

FIG. 5A BREATHING AMPLITUDE (PROCEDURE C)

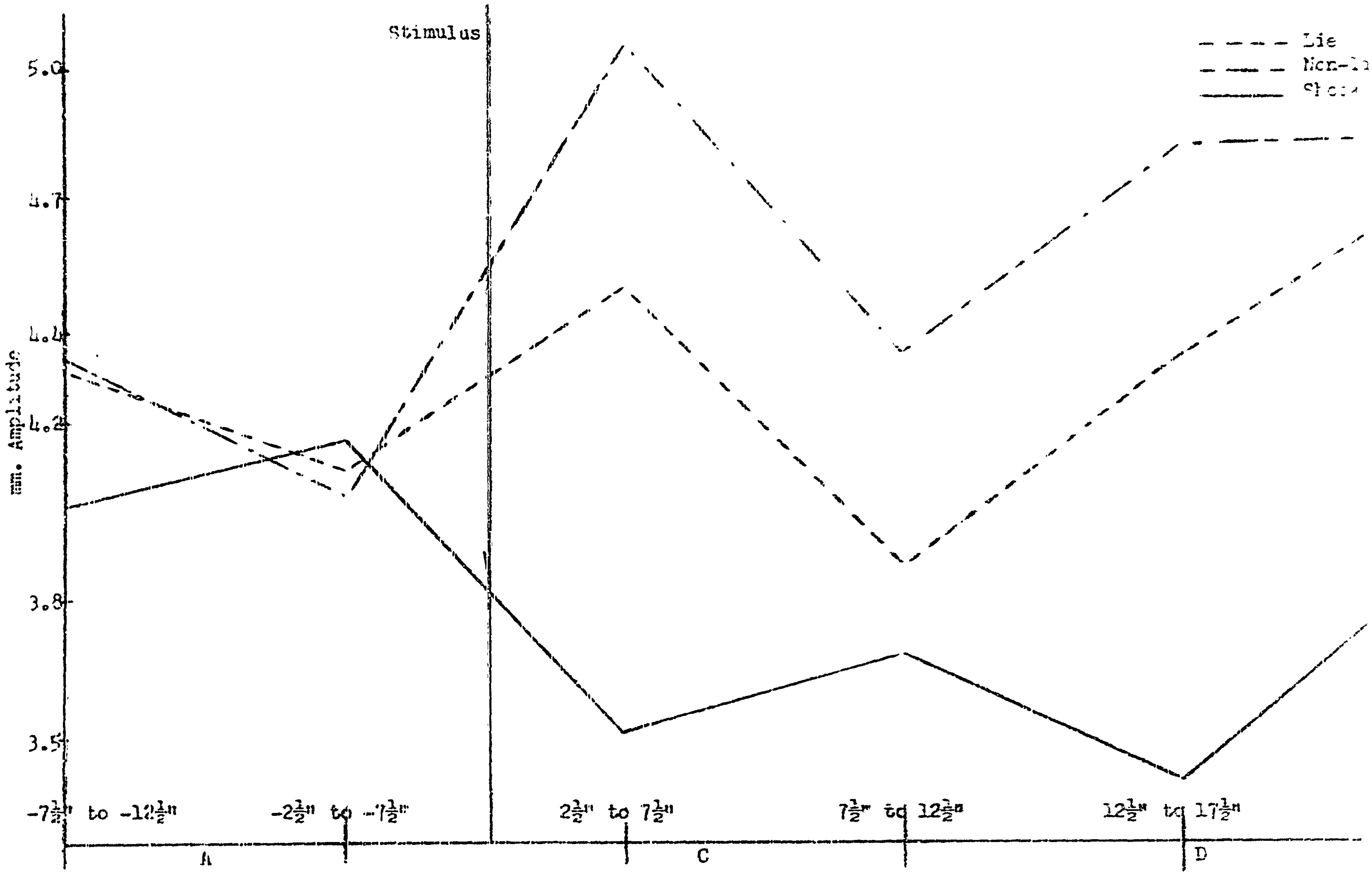
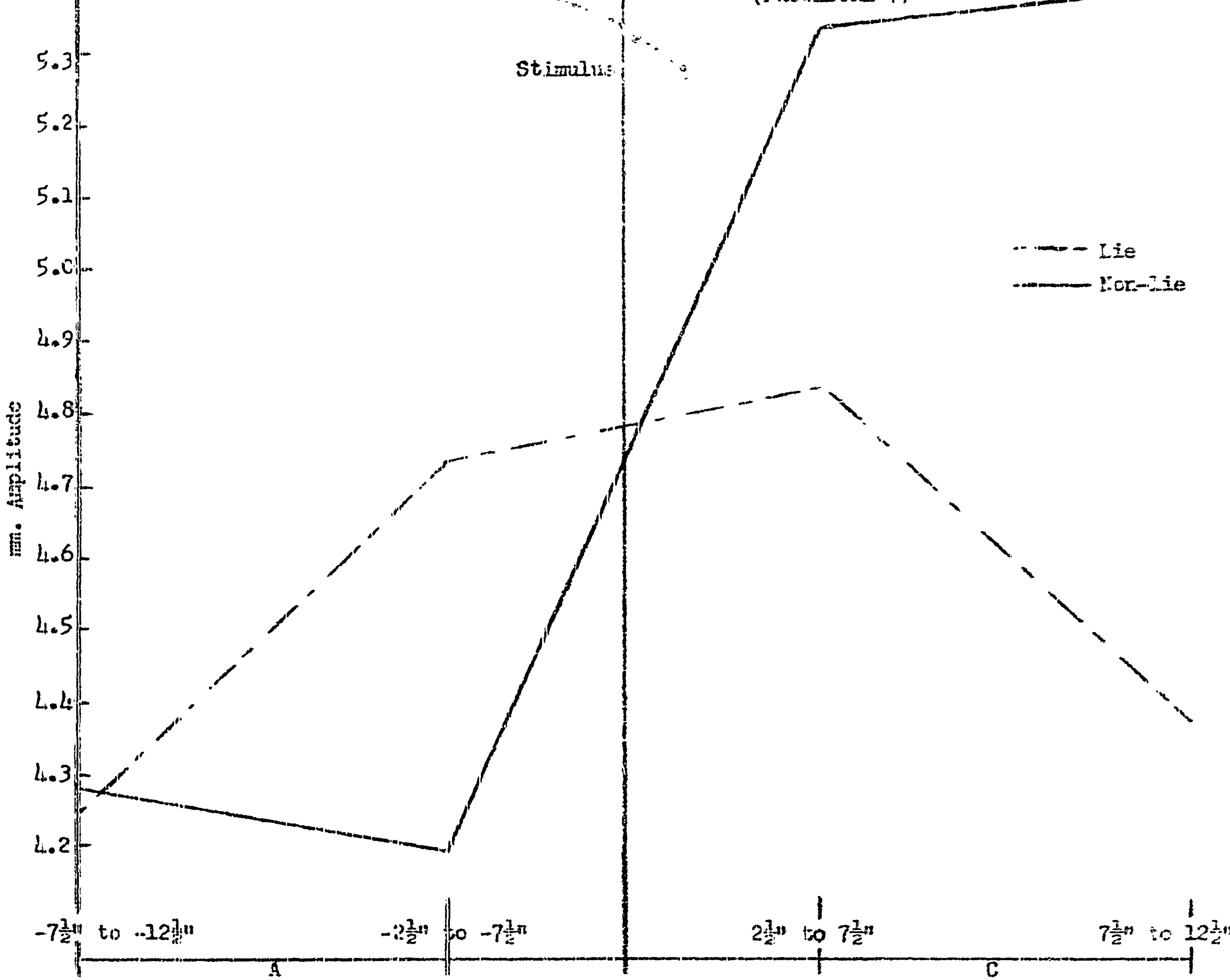


FIG. 55 BREATHING AMPLITUDE
(PROCEDURE 7)



produced by the money questions is in general an increase in depth which is at its greatest during the C-period ($2\frac{1}{2}$" to $12\frac{1}{2}$") after the stimulus. It is impossible to say whether this increase is produced by the necessity for S to answer "yes" or "no", or whether it is associated only with the question. Breathing amplitude is the one function in which the response in the lie situation was less than during the non-lie situation. Consistent with this difference, however, the response to the shock threat is somewhat in the opposite direction. Consequently, the lie response is between the non-lie and shock threat reactions. It may be hypothesized that there are two effects here: questions in general tending to increase depth of breathing with lying and shock threat situations adding an inhibitory effect. The first tendency is evidently the reaction commonly found to a stimulus which also calls forth some movement from the individual. (See section on Breathing Movement Responses.) The second is perhaps to be compared to the checking of breathing during a difficult task such as listening for a sound or to the shallow breathing that appears in certain disease states. Two different neural mechanisms, with opposite effects are quite possibly operating, though at this point one could only guess at their identity.

One might suppose that the requirement that S give a reply was a major factor in producing the increase to the money question. However S also gave a reply to the first shock threat, but showed no increase in amplitude.

For discriminating lying from non-lying the difference between the C-period measure and the A-period measure seems most promising. The interpretation would be, of course, that a smaller difference in the C/A function would indicate lying. A t-test of the difference between lie and non-lie responses for Procedure 6 (using two responses of each kind for each S) gives a value of .51.

Though the difference for the Procedure 6 group is small there was some discrimination, and it was decided to retain the measure for studies of combinations, especially since breathing has been a traditional variable in lie-detection. With such great variability there is, of course, a serious question whether the differences found could be expected to appear regularly. As seen in Fig. 5, the separation was, however, somewhat greater in Procedure 7. The variability (see below) was less, and for Procedure 7 as a whole, this variable was the most discriminative of all those examined.

6. Breathing Rate. The mean results for breathing rate for the Procedure 6 group are shown in Fig. 6. Following the stimulus there was a reduction in rate of breathing for all three situations. The maximum difference between lie and non-lie situations occurs in the D-period about 20-30 seconds after the stimulus. As the difference appeared small and the technique of measurement rather crude, it was decided not to use these data in combinations of measures.

6a. Breathing Time. The second sort of measurement of breathing rate (measuring the times for groups of three cycles) seemed more promising. Fig. 7 shows the mean trends. Since the measurement here is of time the upward trend means a slowing of rate of breathing. Apparently either type of stimulus slows the rate of breathing, with lying producing the greater effect. The maximum difference, in the first period after the stimulus, is significant. For the function (1st post-stimulus minus pre-stimulus) the t-value is 1.7. This measure evidently has some value in discriminating lying from non-lying, at least for the group of subjects tested.

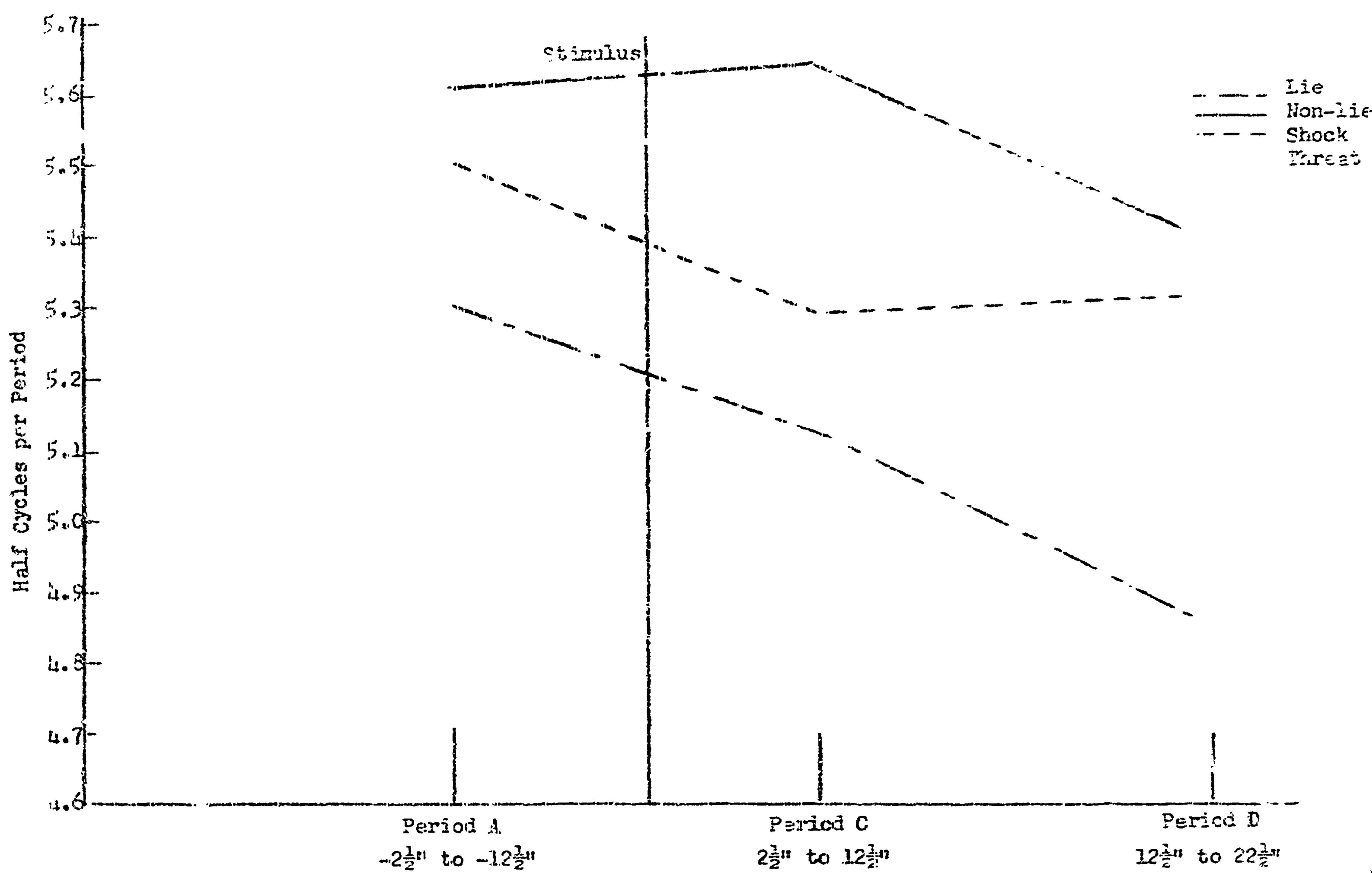


FIG. 6 BREATHING RATE (PROCEDURE 5)

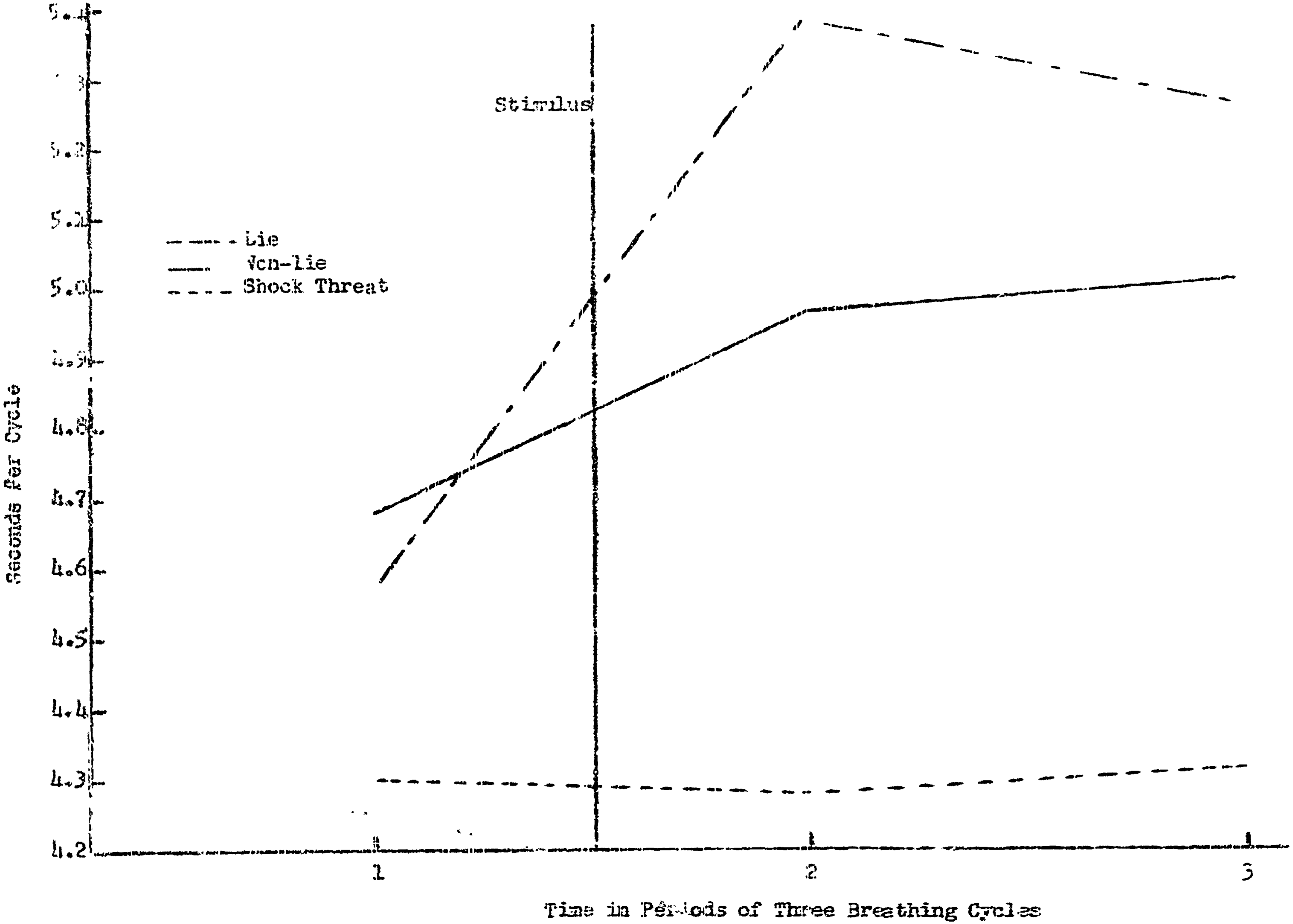


FIG. 7A DURATION OF BREATHING CYCLE (PROCEDURE 6)

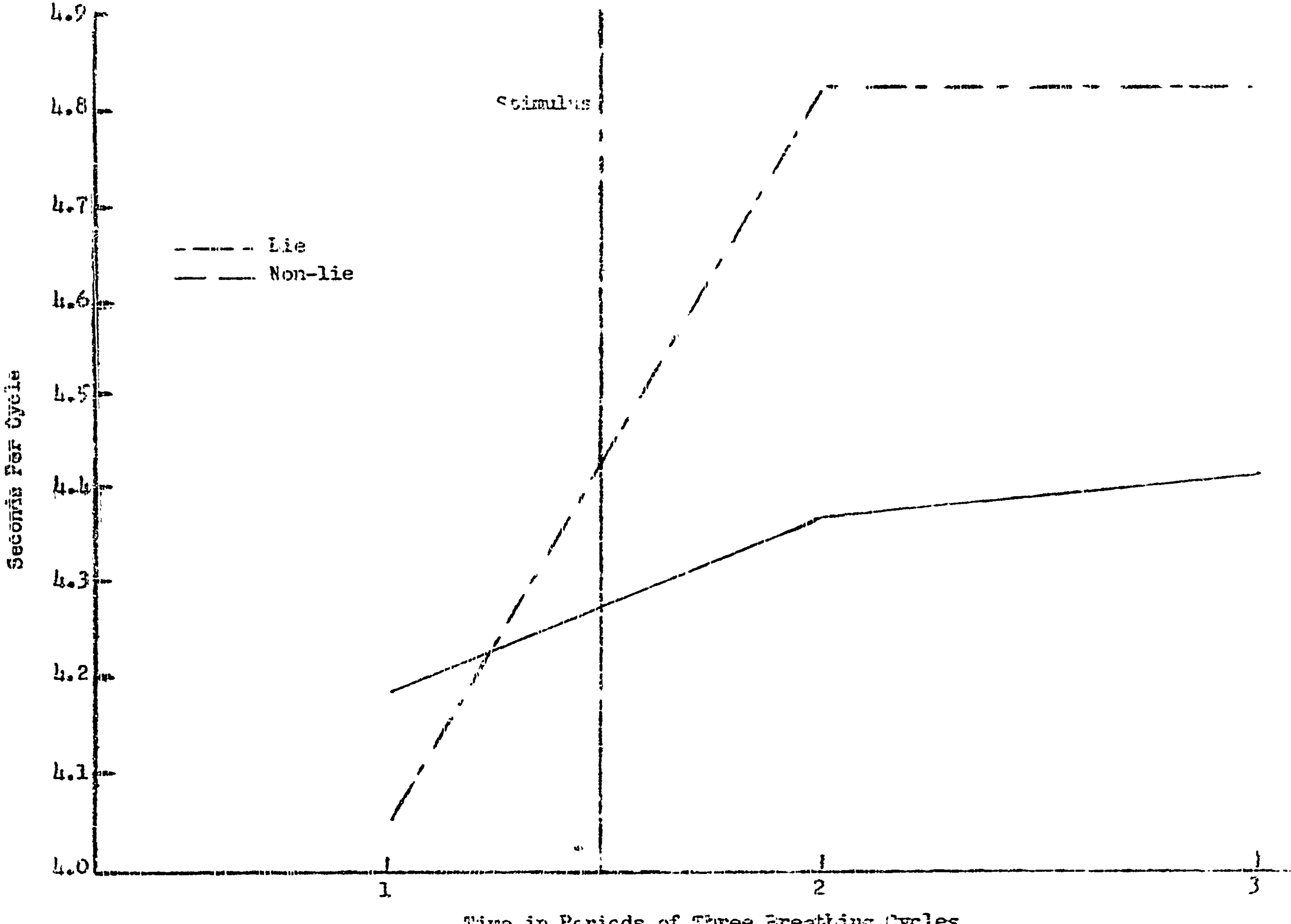


FIG. 7B DURATION OF BREATHING CYCLE (PROCEDURE 7)

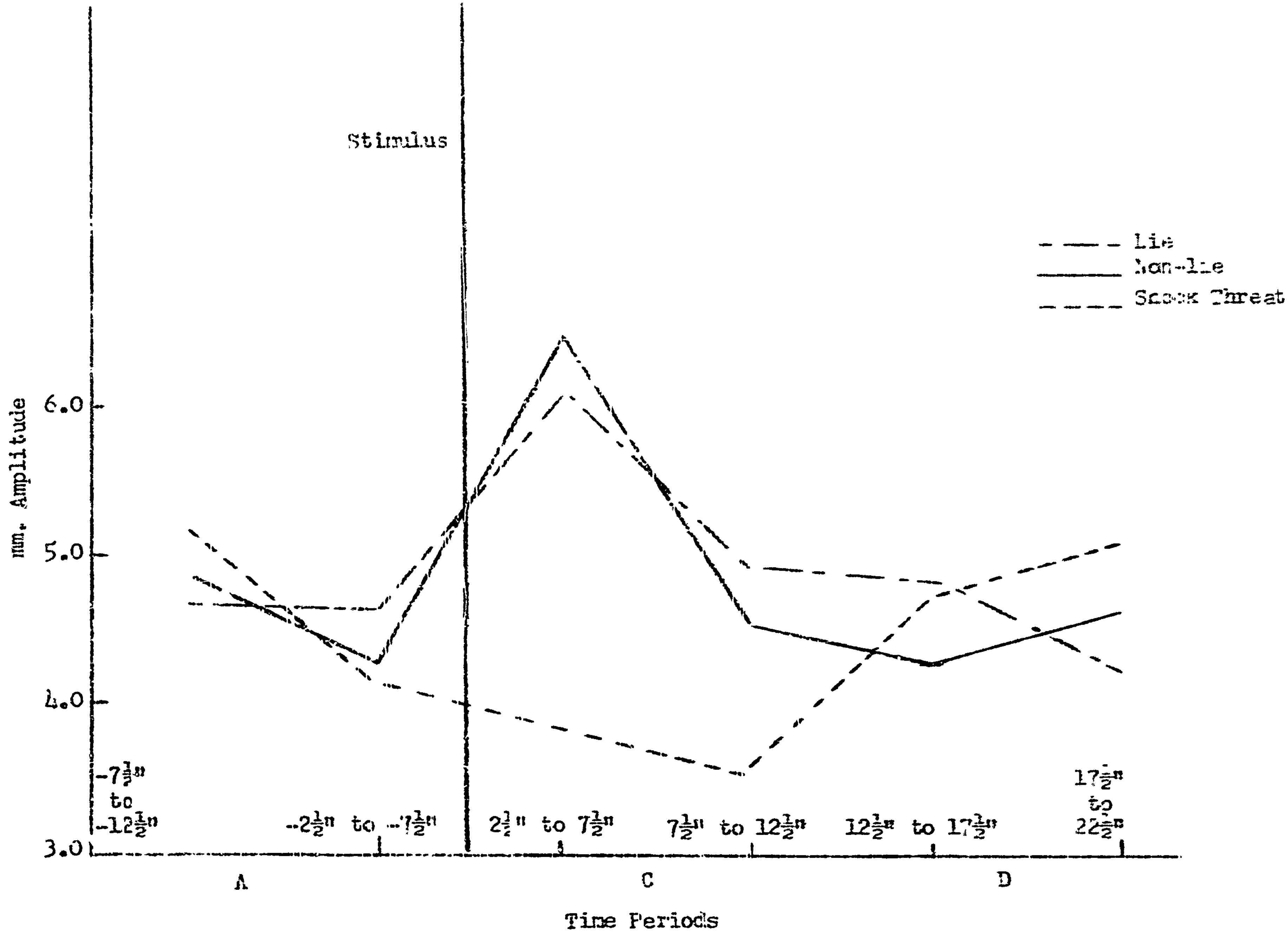


FIG. 8 THERMAL BREATHING AMPLITUDE (PROCEDURE 6)

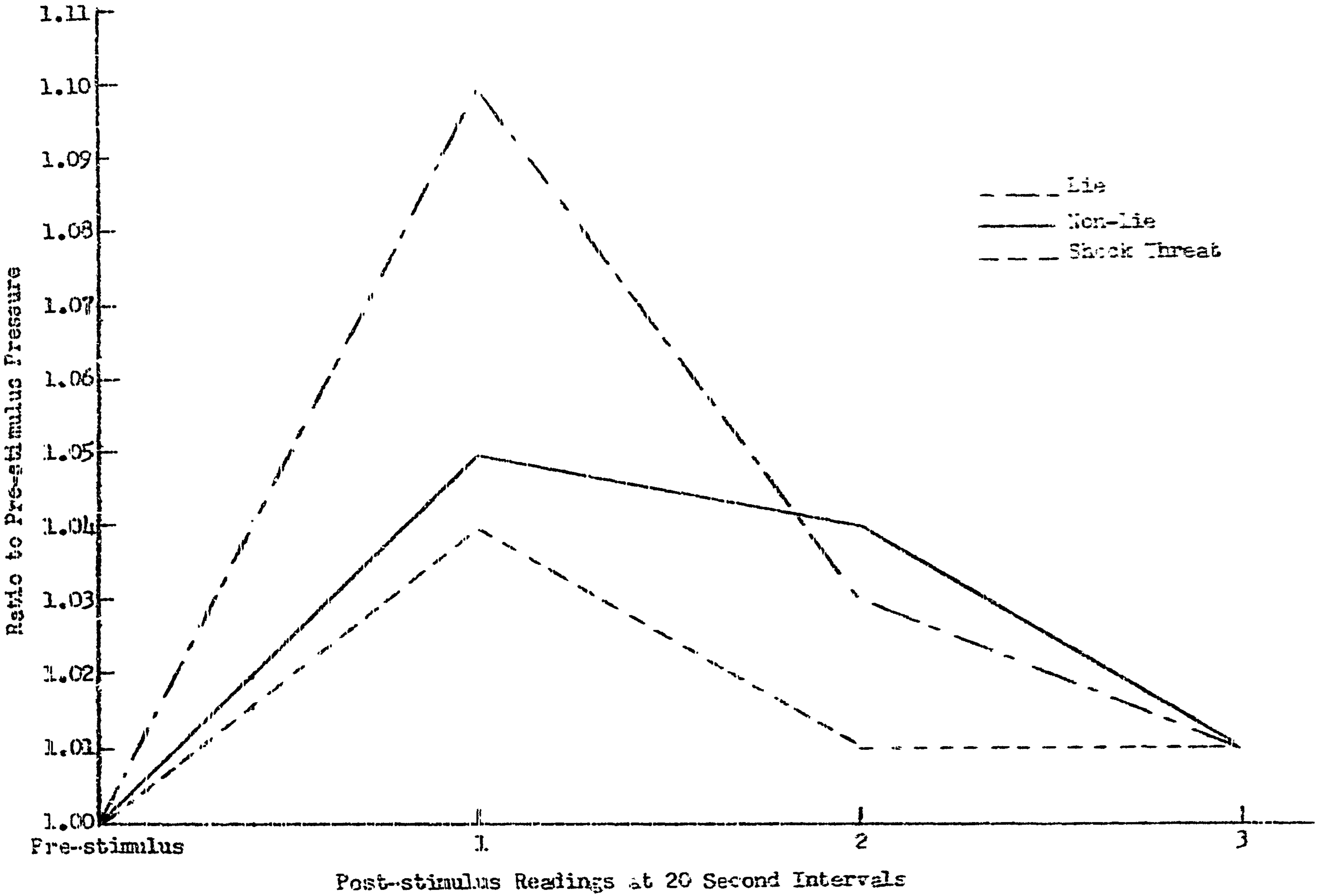
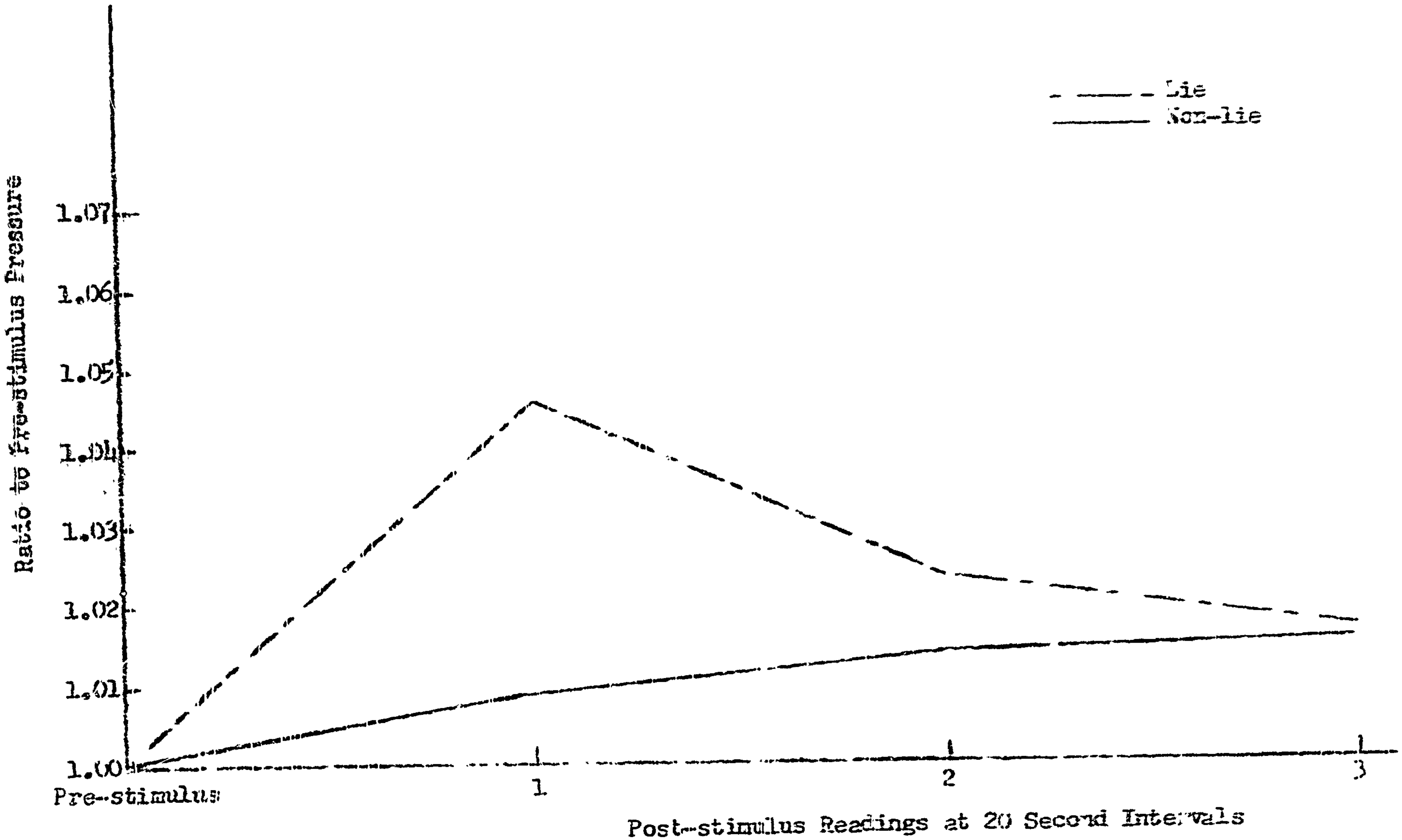


FIG. 9A SYSTOLIC BLOOD PRESSURE CHANGES (PROCEDURE 6)

FIG. 9B SYSTOLIC BLOOD PRESSURE CHANGES (PROCEDURE 7)



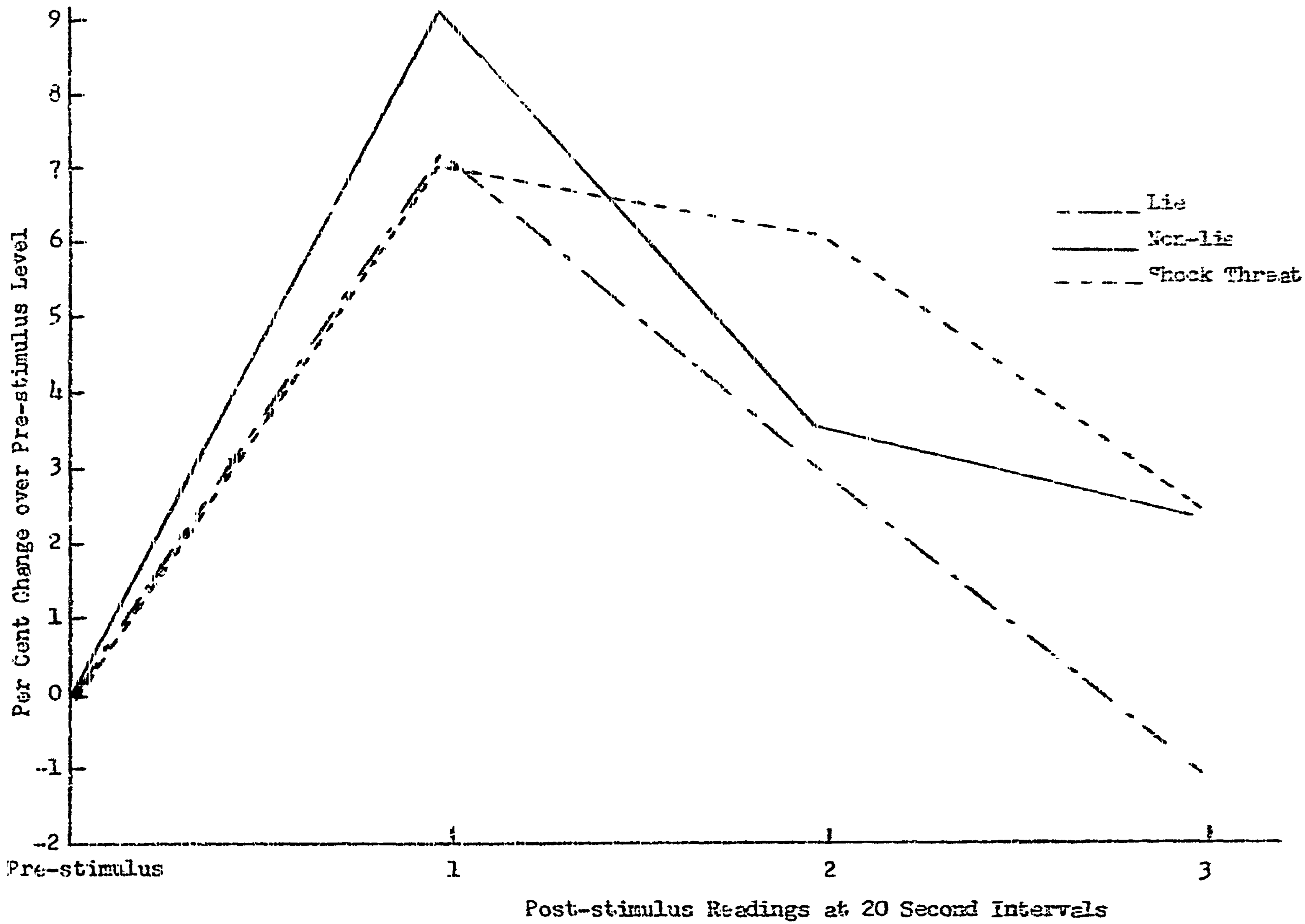


FIG. 10 DIASTOLIC BLOOD PRESSURE CHANGES (PROCEDURE 6)

10. Pressure Pulse. The responses found in our measures of pressure pulse (Fig. 11) vary in the same way as do the systolic pressure responses (Fig. 11). They are small for shock threat, medium for non-lie, and greatest for lie. There is however, considerable variability, some of which probably arises from recording technique. The measure was not used in the pattern analysis, but was included in other studies of combinations. Fig. 11 shows the difference for Procedure 7 was less than for Procedure 6. With better quantification, however, the measure might have considerable value, and could quite possibly replace the more cumbersome systolic measure.

11. Pulse Rate. The measurements of pulse rate by the first method tried were chiefly notable for their irregularity. Though some consistencies of response appeared, it seemed likely because of results obtained in Procedure 4 that the method of measurement was at fault. Therefore all records were remeasured in the manner described as variable 12 before further analysis.

12. Pulse Time. Although this sort of measurement cannot be located definitely in time it has the advantage that no approximation of fractions of a pulse cycle are required. It may also be an advantage that in averaging, corresponding pulse beats are added together. (It may be that responses in the circulatory system are best referred to its own time scale.) Fig. 12 shows the pulse time responses to the various situations for both groups. In the first five pulses after the stimulus there may be an acceleration followed by a very clear slowing of the pulse rate below normal. This is evidently the same kind of response described as a feature of Type I cardiovascular response in an earlier section. The deceleration is greater for lying than non-lying, and is still greater for the shock threat situation. The largest difference between the lying and non-lying responses (Procedure 6) is brought out by subtracting the first post-stimulus measure from the third. A t-test of the difference between lying and non-lying for this function gives a value of 3.54. In studying some combinations of measures this function (3d minus 1st post-stimulus measure) was used. In the "pattern analysis" the two were entered separately, on the grounds that they would be properly combined automatically in that calculation.

13. Pulse Volume Amplitude. The mean responses for the pulse volume measure are shown in Fig. 13. (The measurements plotted for the Procedure 6 group are those made in the manner already described. Those plotted for Procedure 7 (Fig. 13B) were made according to the plan described in the section on cardiovascular responses. The height of each pulse was measured and the average computed for the 1st pulse, 2nd pulse, etc. In the statistical analysis, however, the same type of measure was used for Procedure 7 as for Procedure 6.) The response to all of our stimuli is one of diminished pulse size. According to the analysis given in the section on cardiovascular variables this signifies a vasoconstriction, a part of the Type I reaction there described. The response begins a few seconds after the stimulus and reaches its greatest size about 10" after the stimulus. Recovery is slow, being incomplete even 30" after the stimulus. All situations produce nearly, though not quite, the same amount of decrease in the pulse size. The reason may be that a maximum vasoconstriction is rather easily produced by these stimuli, so that it occurs in nearly all cases. Differences between stimulus effects show up more in the recovery period. Shock threat responses are slowest to recover, non-lie responses are most rapid, and lie responses intermediate. Since the greatest lie-non-lie difference appears in the D-period (12.5" to 22.5" after the stimulus), the mean of this period was taken

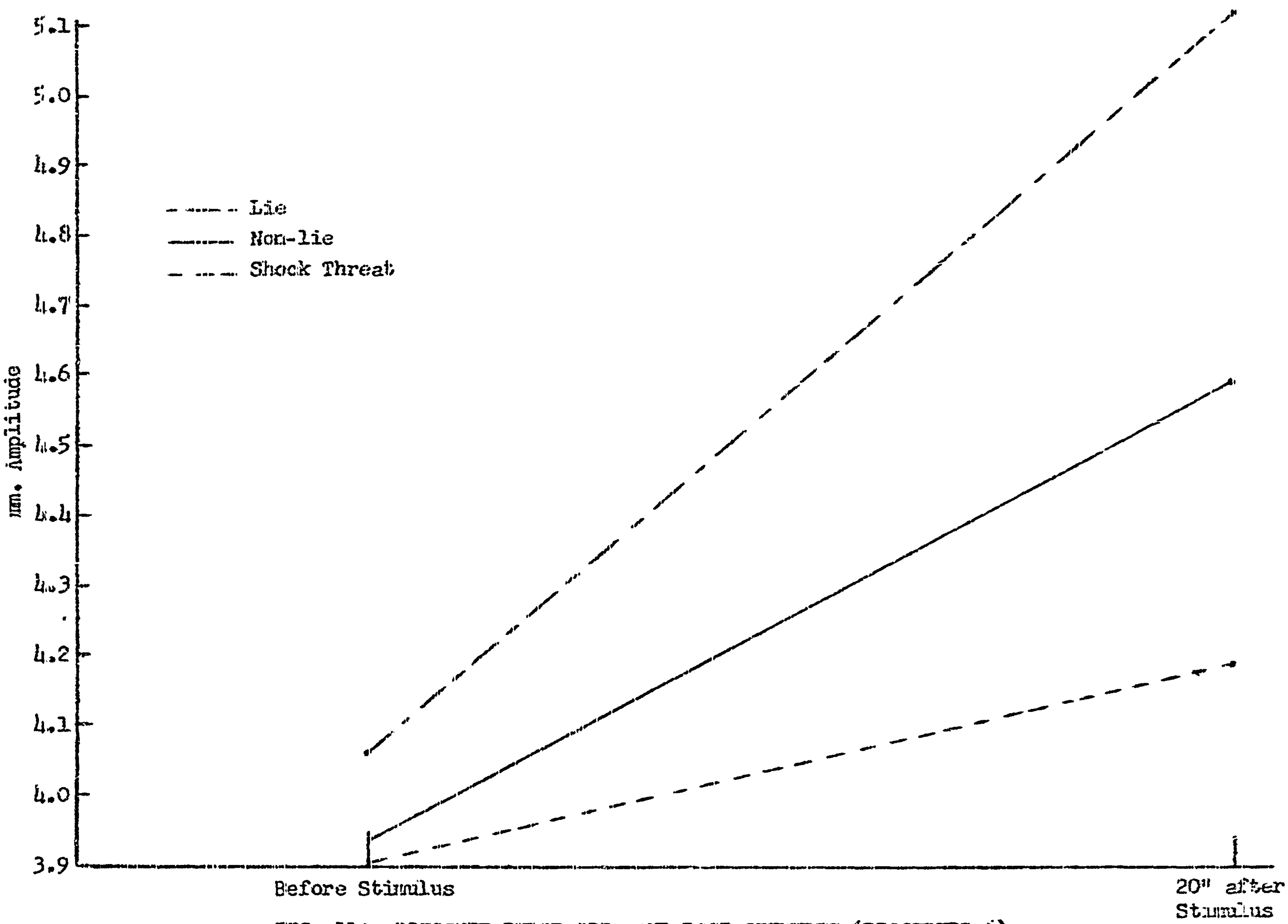


FIG. 11A PRESSURE PULSE PRE- AND POST-STIMULUS (PROCEDURE 6)

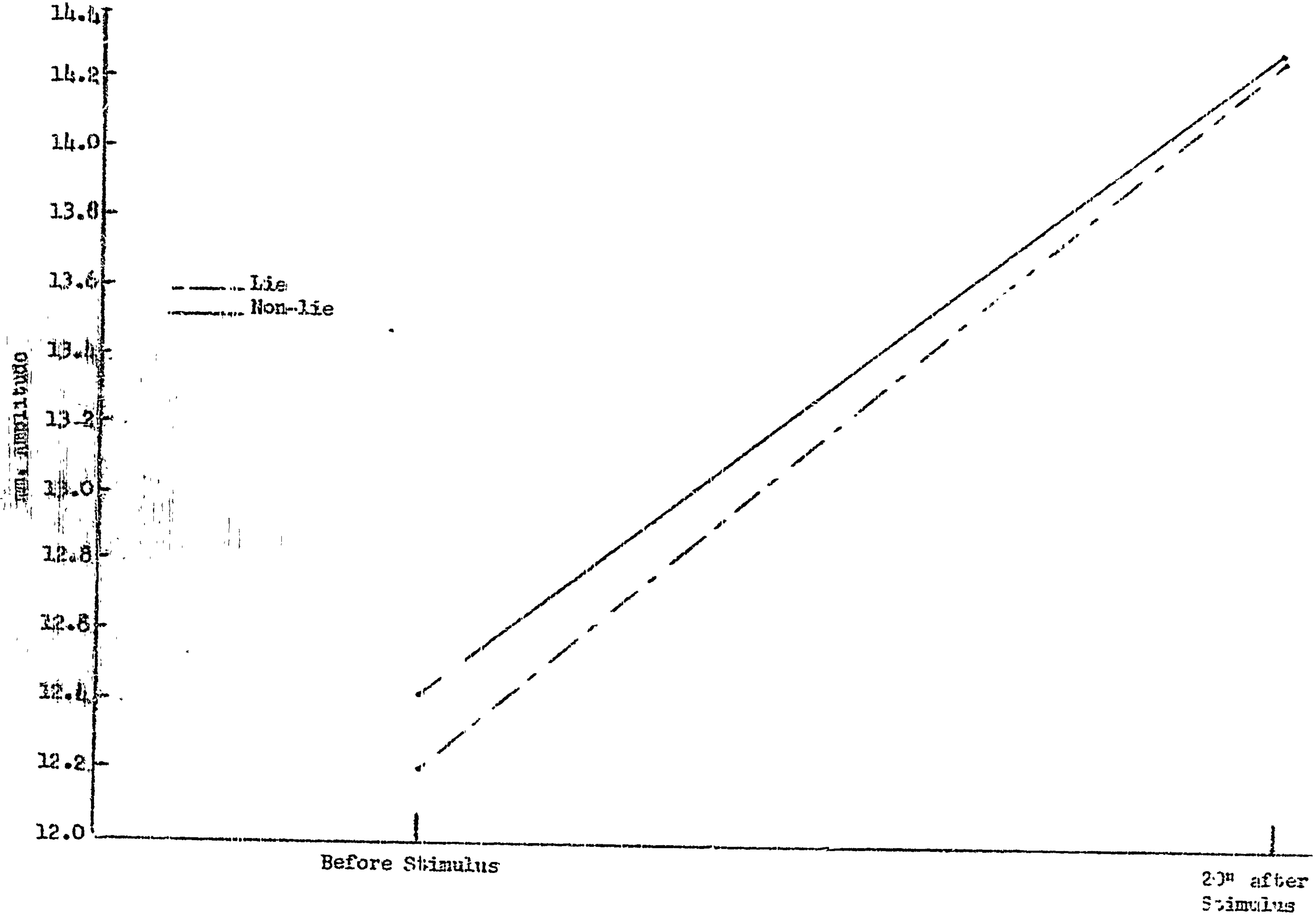


FIG. 11B PRESSURE PULSE PRE- AND POST-STIMULUS (PROCEDURE 7)

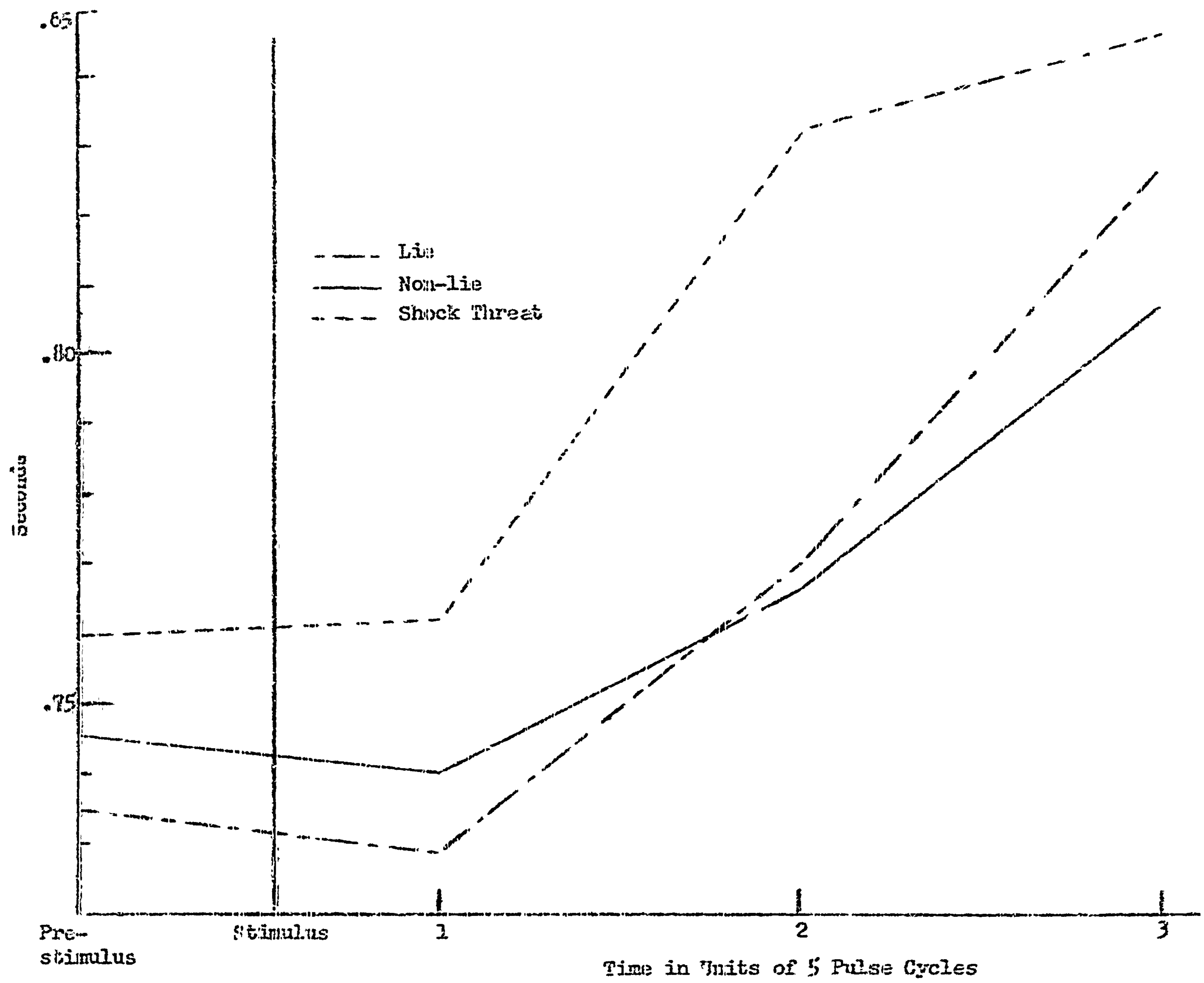


FIG. 12A INTER PULSE INTERVAL PRE- AND POST-STIMULUS (PROCEDURE 6)

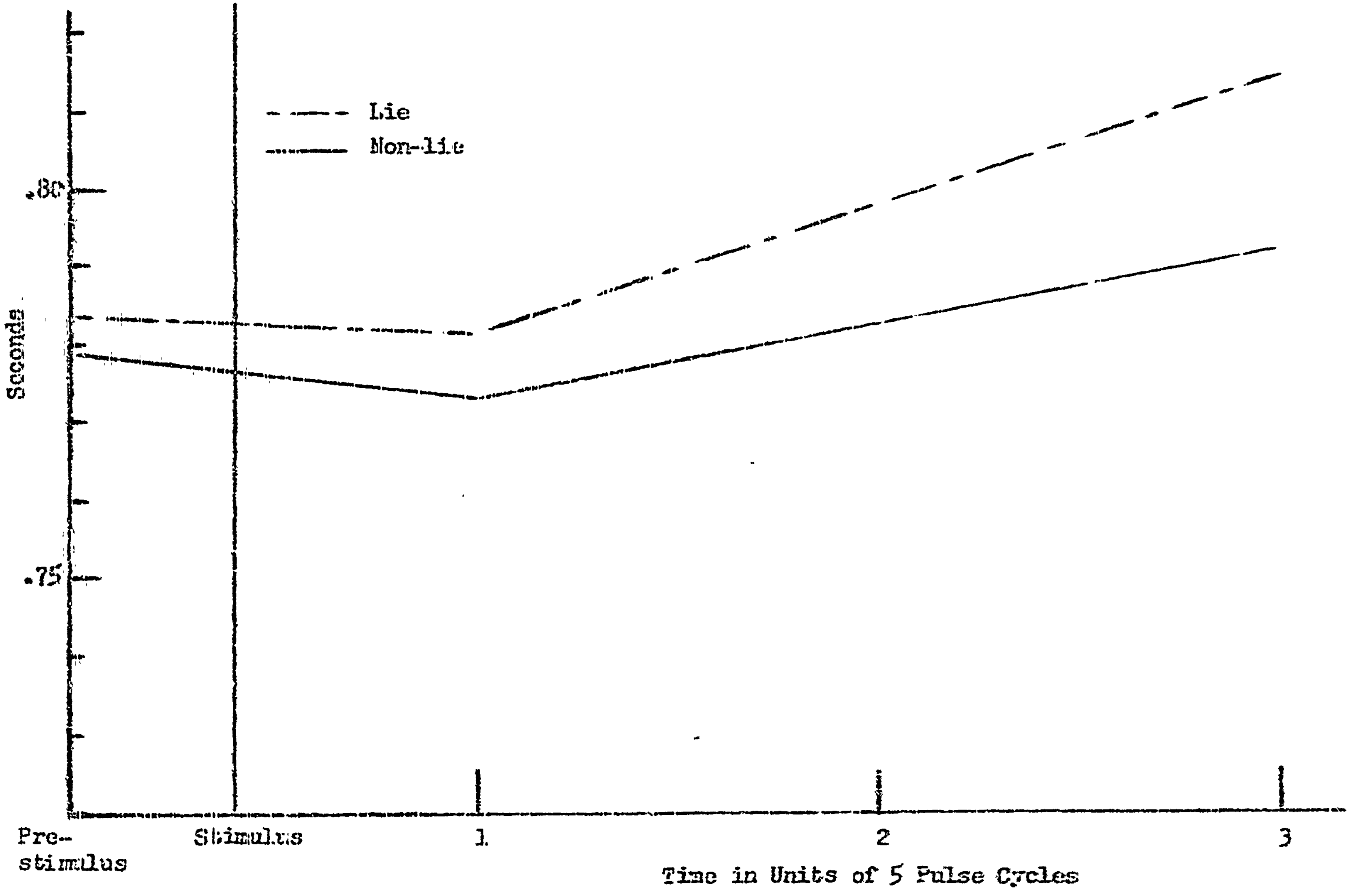


FIG. 12B INTER PULSE INTERVAL PRE- AND POST-STIMULUS (PROCEDURE 7)

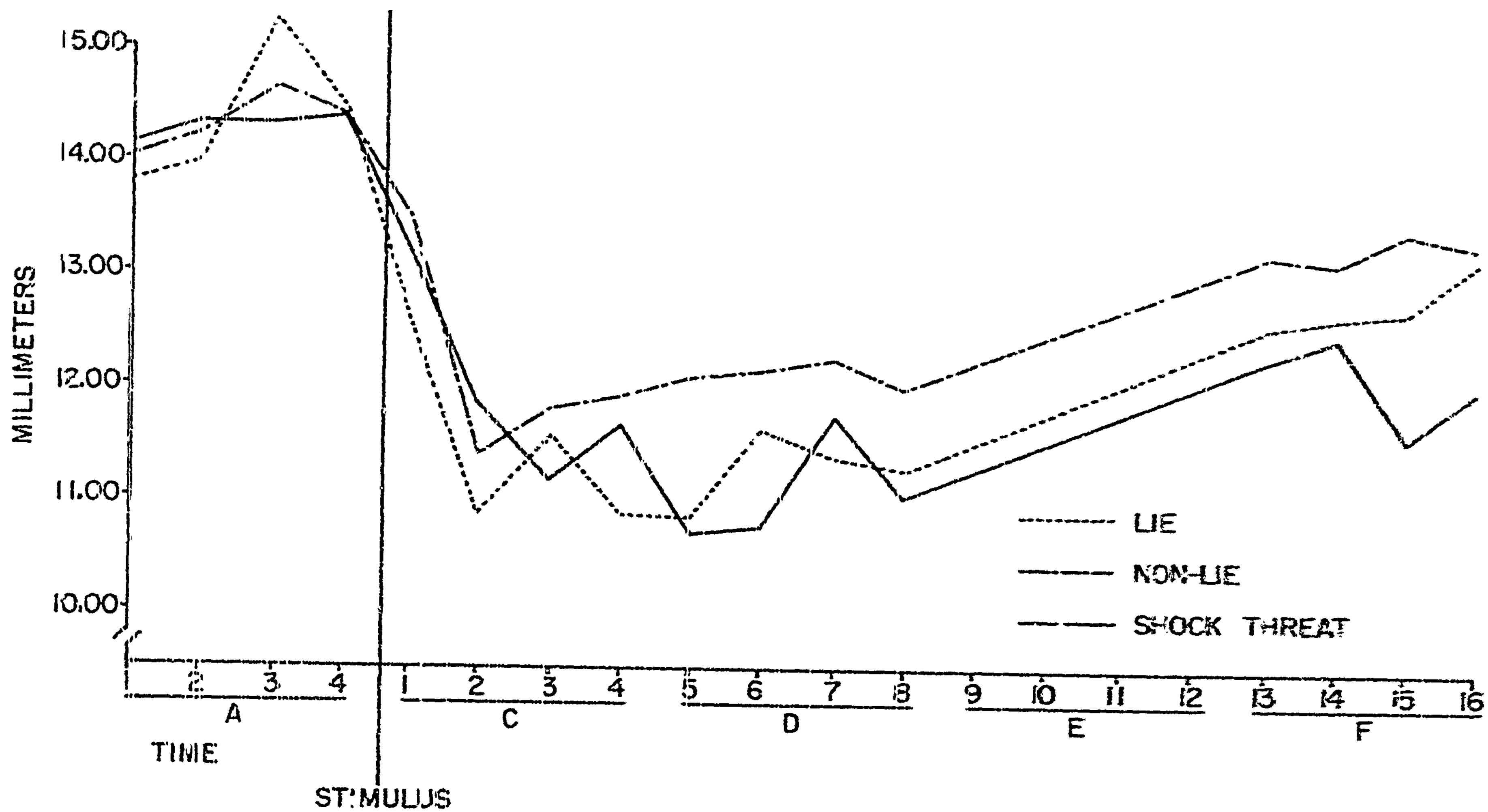
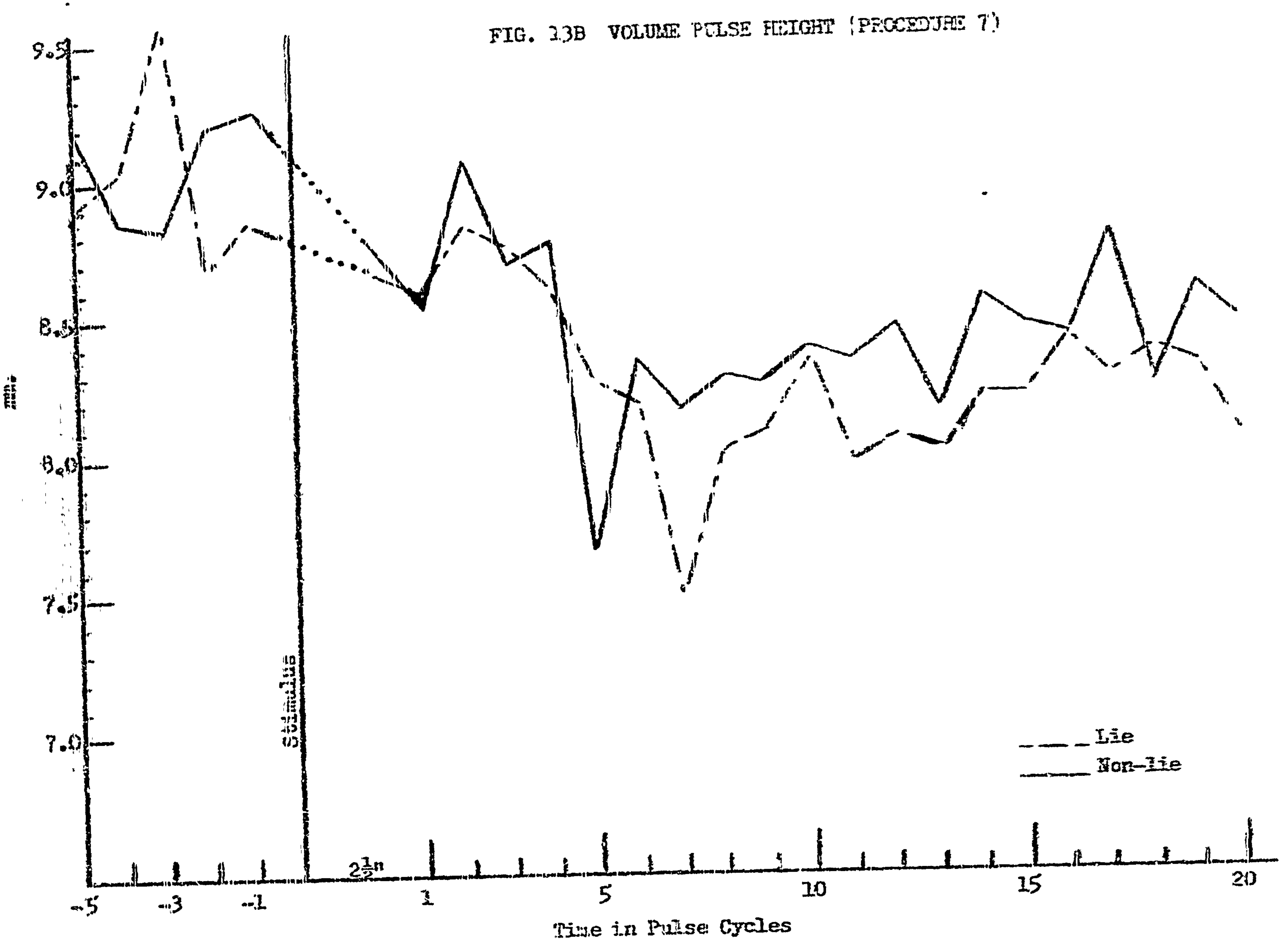


FIG. 13A VOLUME PULSE CHANGES
MEAN OF 59 CASES
TIME UNIT = $2\frac{1}{2}$"

FIG. 13B VOLUME PULSE HEIGHT (PROCEDURE 7)



as the principal measure in further studies. To adjust for initial level the difference between the A and D means was used for most purposes. In the "pattern analysis" the two means were entered separately, however. For Procedure 6 the lie-non-lie difference in the A-D function has a t-value of .73.

It seems probable, from inspection of the records, that a good deal of the variability of this function is produced by unequal pre-stimulus conditions. Quite often the stimulus was delivered when the pulse size was already diminished. Sometimes it had not recovered from the constriction of the previous stimulus. In many individuals, further, there are many "spontaneous" vasoconstrictions very much like the responses to the intentional stimuli. The experimenter would probably do well to wait for recovery before administering the next stimulus. This precaution is especially important in a variable which has a "ceiling" so easily reached.

One may consider all variables together in attempt to construct a picture of the physiological changes produced by our stimuli. The following statements summarize the effects for our S's:

1. All stimuli produce a change in all the variables studied (excepting possibly the shock threat-breathing response combination).

2. All (mean) stimulus effects on each physiological variable are in the same direction.

3. In the cardiovascular system the response is of the sort we have called Type I response, involving peripheral vasoconstriction, cardiac deceleration (possibly preceded by a slight acceleration) and increased systolic, diastolic and pulse pressures. The breathing, with the exception noted, becomes slower and deeper, perhaps fundamentally by reason of exaggerated pauses before inspiration. The palmar sweating mechanism is activated.

4. In pulse time, and volume pulse amplitude, shock threat produces a greater response than either lying or non-lying responses to the money questions. This would probably be true of the g.s.r. also were it not that adaptation had weakened the response by the time shock threats were given. In breathing responses the order is reversed: shock threat producing least and non-lies the greatest change. In the three blood pressure variables shock threat produces very little response, while lying produces the greatest. (See below for probable absence of adaptation.) Except for the blood pressure measures, therefore, the lie response may be expected to be intermediate between the non-lie and the shock threat.

5. In all cases except breathing amplitude the effect peculiar to lying is to exaggerate the response produced by a non-lie question. (diastolic pressure here disregarded). In breathing amplitude lying and shock threat inhibit the response produced by a question.

Table I shows something of the discriminative power (lie vs. non-lie) of the various measures taken singly. The "Discrimination Ratio" is the mean difference squared divided by the S.D. of the differences by subjects. This ratio is the one which pattern analysis maximizes for combinations of measures. It is useful therefore in comparing combined with single variables. The "Percentage of Detection" is the percent of the individuals for whom the

TABLE I

DISCRIMINATION (LIE vs NON-LIE) SHOWN BY VARIOUS SINGLE VARIABLES

Variable	Procedure 6		Procedure 7	
	Per Cent Detection	Discrimination Ratio	Per Cent Detection	Discrimination Ratio
GSR I	60	.05	60	.001
GSR II	77	.23	70	.057
GSR I Time	59			
GSR II Time	43			
Breathing Amp.	57	.01	77	.430
Breathing Rate	68			
Breathing Time	63	.11	68	.137
Systolic Pressure I	66	.12	72	.211
Diastolic Pressure	55			
Pressure Pulse	64	.05	62	.002
Pulse Time	68	.23	64	.164
Volume Pulse	66	.02	55	.002

lie-non-lie difference has the same sign as the average difference: in other words these also show the tendencies described above as typical.

The percentages of detection are lower than those found in the more successful of experiments of other investigators, and lower than those found in our own special experiments (on the g.s.r. for example). The absolute values should not, however, be taken to apply to these measures in general. As already suggested it is probable that the situation used in this particular experiment is a rather poor one for eliciting the lying response. The purpose of this experiment is served quite well of course by these rather low percentages, since they allow room for improvement by combinations, if such improvement is possible.

In Procedure 6, G.S.R. II from the left hand is clearly the best single variable, and it is one of the best in Procedure 7. Among the other variables whose study was pursued there is little to choose on the basis of percent detection in Procedure 6. Some notable changes in the relative values occur in Procedure 7. The major reason for these is discussed below.

Serial Position Effects

If there are serial position effects they must be taken into account in making comparisons between responses in trying to discriminate between lies and non-lies. Should questions early in a series produce larger responses, for example, a lie or non-lie response coming in that part of the series would have to be discounted before it could be compared with one in the later part of the series.

Accordingly the data were examined for serial position effects. The mean response to each question was plotted for each variable for questions 5-14 (Procedure 6). To avoid averaging lie-and-non-lie-responses the S's were divided into two groups: those who took dimes, and those who took quarters.

Fig. 14 shows the results for the g.s.r.'s in Procedure 6. It is immediately apparent that there is a great deal of similarity in the two sets of responses for each g.s.r. channel (and between channels as well). The same variations, more pronounced, if anything, appear in the time measures for the g.s.r. (not graphed). There seems to be a basic pattern of alternate large and small responses.

There were, it will be remembered, two forms of question used, and it might be supposed that differences in their effects contributes to the serial pattern. However, comparing responses to the two forms we find no difference. The mean response to the one kind of question is .1230 and to the other .1236. Obviously this factor is of no consequence in the present data. (In general, however, there might be a small difference in the effect of the two forms of question. In our experiment questions beginning "Are the ... " came, on the average, a little later in the series, and their effects may have been slightly weakened by that fact.)

Some information on the effect of the coin denomination mentioned may be found in the g.s.r. data from Procedure 7. Here the mean position is about the same for each denomination. Responses to "5¢ questions" and "50¢

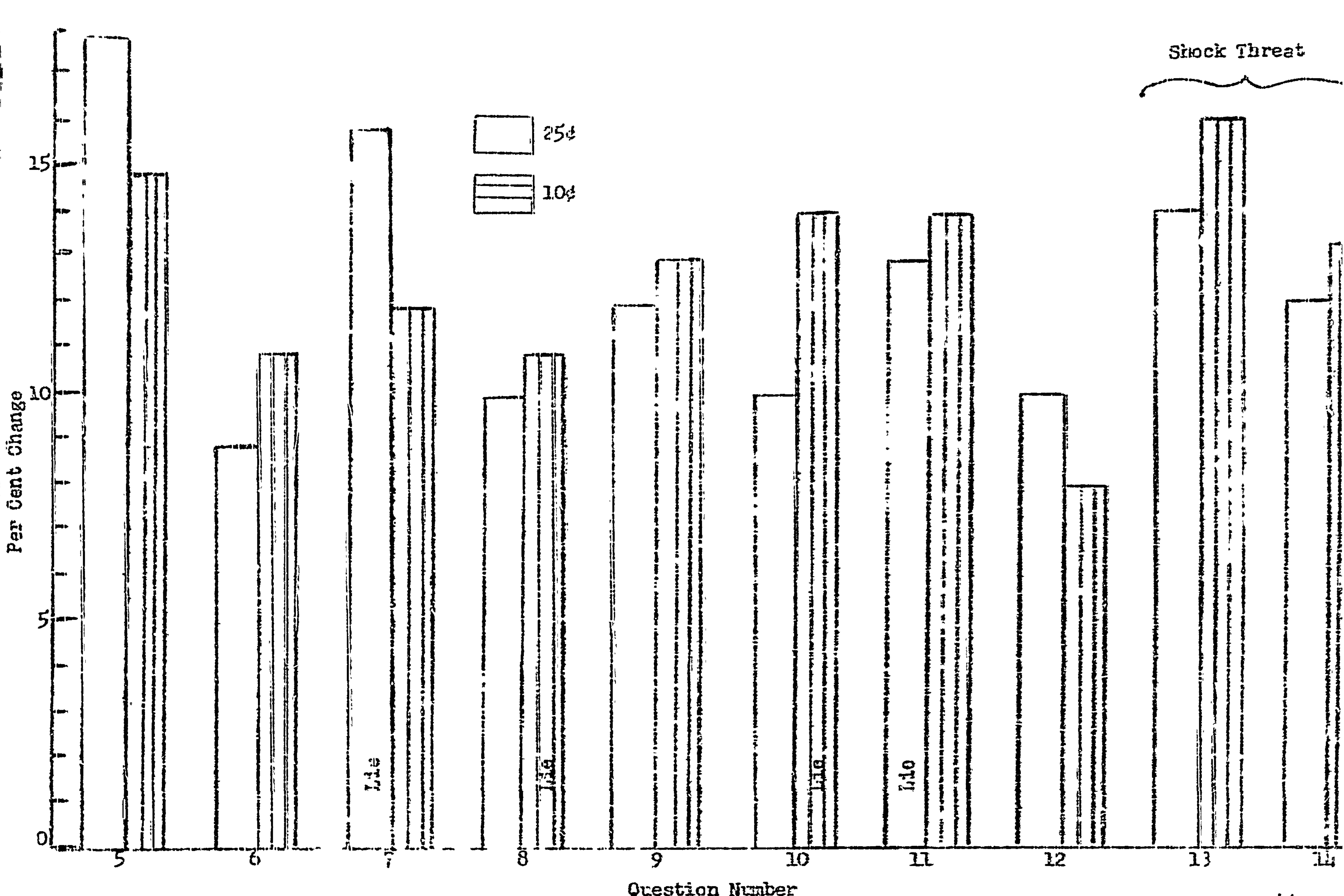


FIG. 14A G.S.R. I AMPLITUDE TO QUESTIONS 5-14 (PROCEDURE 6)

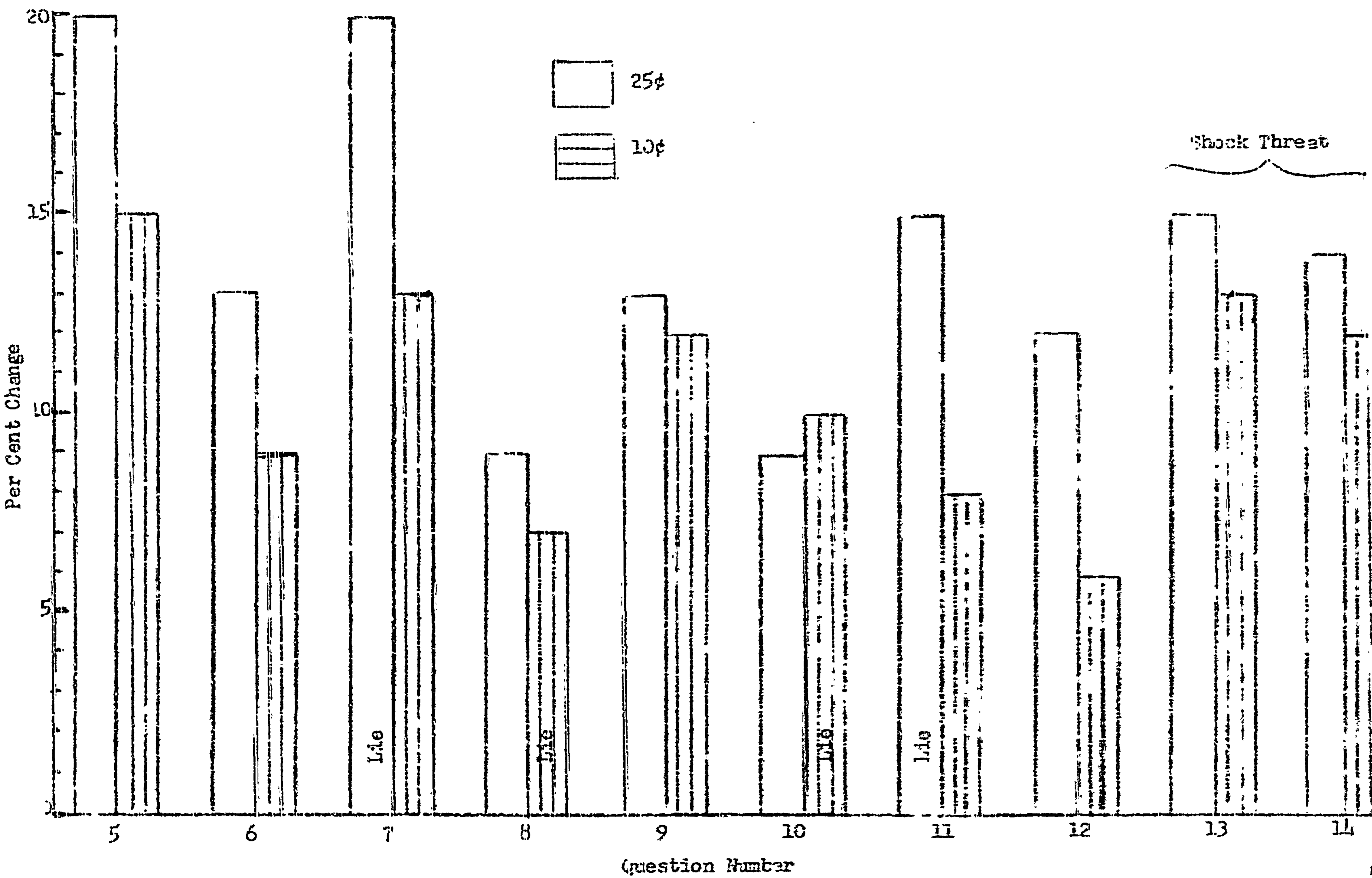


FIG. 14B G.S.R. II AMPLITUDE TO QUESTIONS 5-14 (PROCEDURE 6) questions" of course involved no lies in this group. The means are respectively .207 and .161 for G.S.R. I and .220 and .190 for G.S.R. II. The 10¢ and 25¢ questions, both involving lies on the part of some S's, averaged .225 and .227 for G.S.R. I, and .208 and .223. For this group, at least, the questions involving 50¢ produce somewhat less response than those involving 5¢, while 10¢ and 25¢ questions have about equal effects. Some of the systematic variation with serial position may, therefore, be referred to the difference in stimulation effect of the denominations mentioned.

In the Procedure 6 g.s.r. data there is a suggestion of a decrease in response size as the series progresses. More complete information is available from Procedure 7 data, since each question appeared once in each third of the list, and each third contained an equal number of lies. Fig. 15 is a plot of the mean response for each third of the list. It is evident that there is a tendency for responses to diminish as the series goes on. This is, of course, a common finding in g.s.r. work.

In certain other measures there is a suggestion of the same positional or question-content effect as seen in the g.s.r. Fig.16A-D shows the mean trends for four important variables used in combinational studies. In breathing amplitude and volume pulse amplitude, questions 7 and 11, for example, favor a mean response which looks like a lie response whether they are associated with lying or not. Systolic pressure and pulse time seem not to be affected in this manner. For the majority of our variables, then, there are responses such that on questions 7 and 11 lying effects will be superimposed on reactions which would be large in any case, while for questions 8 and 10 they will be superimposed on responses which are otherwise small (compared to 7 and 11).

Considering these facts one must observe certain precautions in comparing lie and non-lie responses. (1) The wearing out of the response must be allowed for. (2) Lie and non-lie questions must be the same, or of equal stimulating value. For these reasons, in our principal analyses of data only 10¢ and 25¢ questions were considered, there being some lies and some non-lies in response to each. In Procedure 6 the mean serial position of the 10¢ questions was the same as that of the 25¢ questions. In Procedure 7 there was a difference, probably negligible, of one position. This technique would neutralize position and content effects to a great extent.

Effect of Repetition of Questions

Table I shows no consistent improvement between the discrimination found in Procedure 6 and that found in Procedure 7. This is surprising because one would expect that the increased reliability provided by repeating the questions would improve the discrimination. To examine this matter further the data from Procedure 7 was divided into three segments, each containing a complete cycle of money questions. Lie minus non-lie scores were computed for each variable for the first segment and from the first two segments for comparison with the score from all three. Table II shows the percentages of discrimination for these combinations. The only variables to show a substantial increase with the inclusion of additional readings are systolic pressure and breathing amplitude.

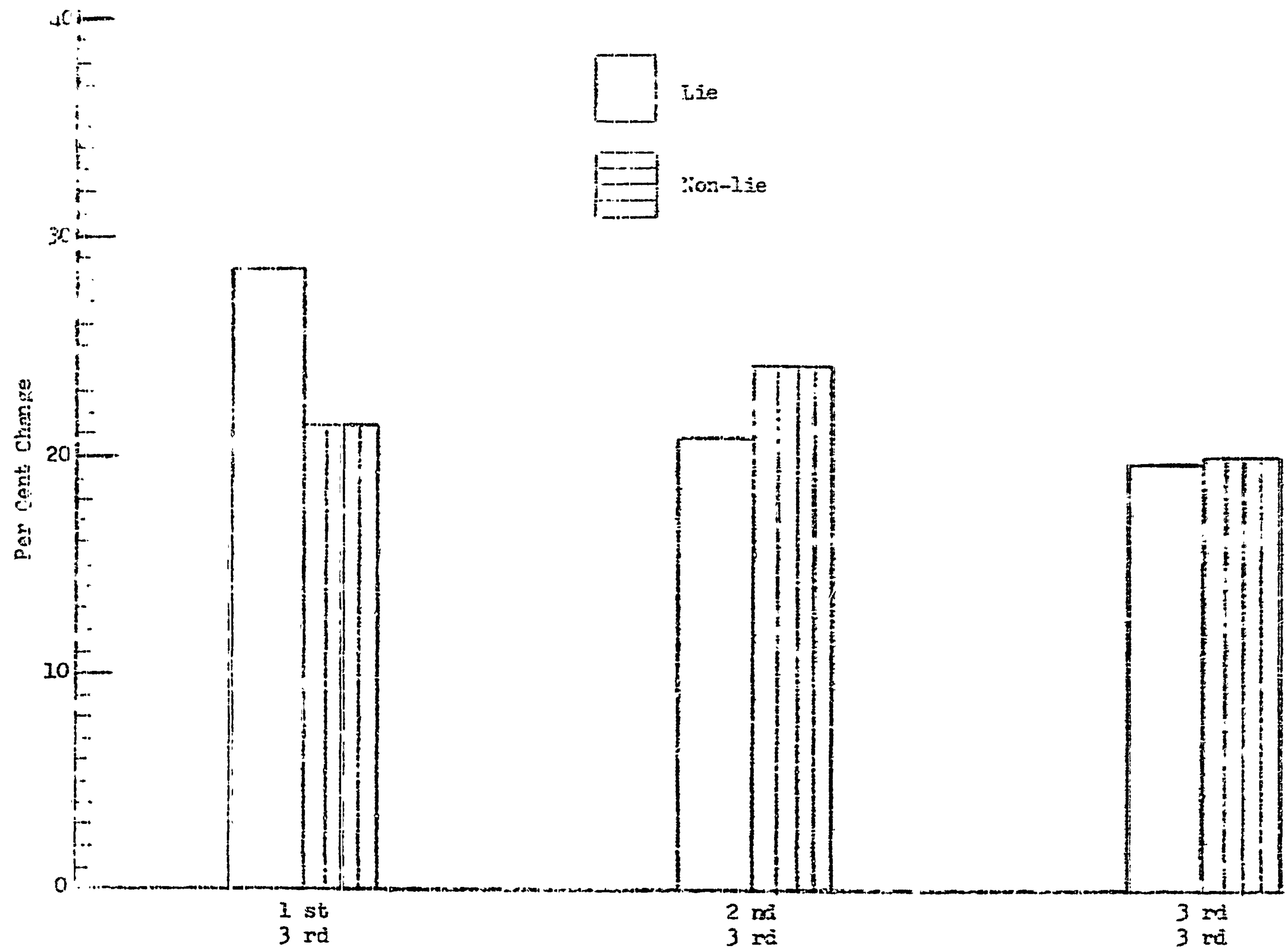


FIG. 15A G.S.R. I IN SUCCESSIVE THIRDS OF PROCEDURE 7

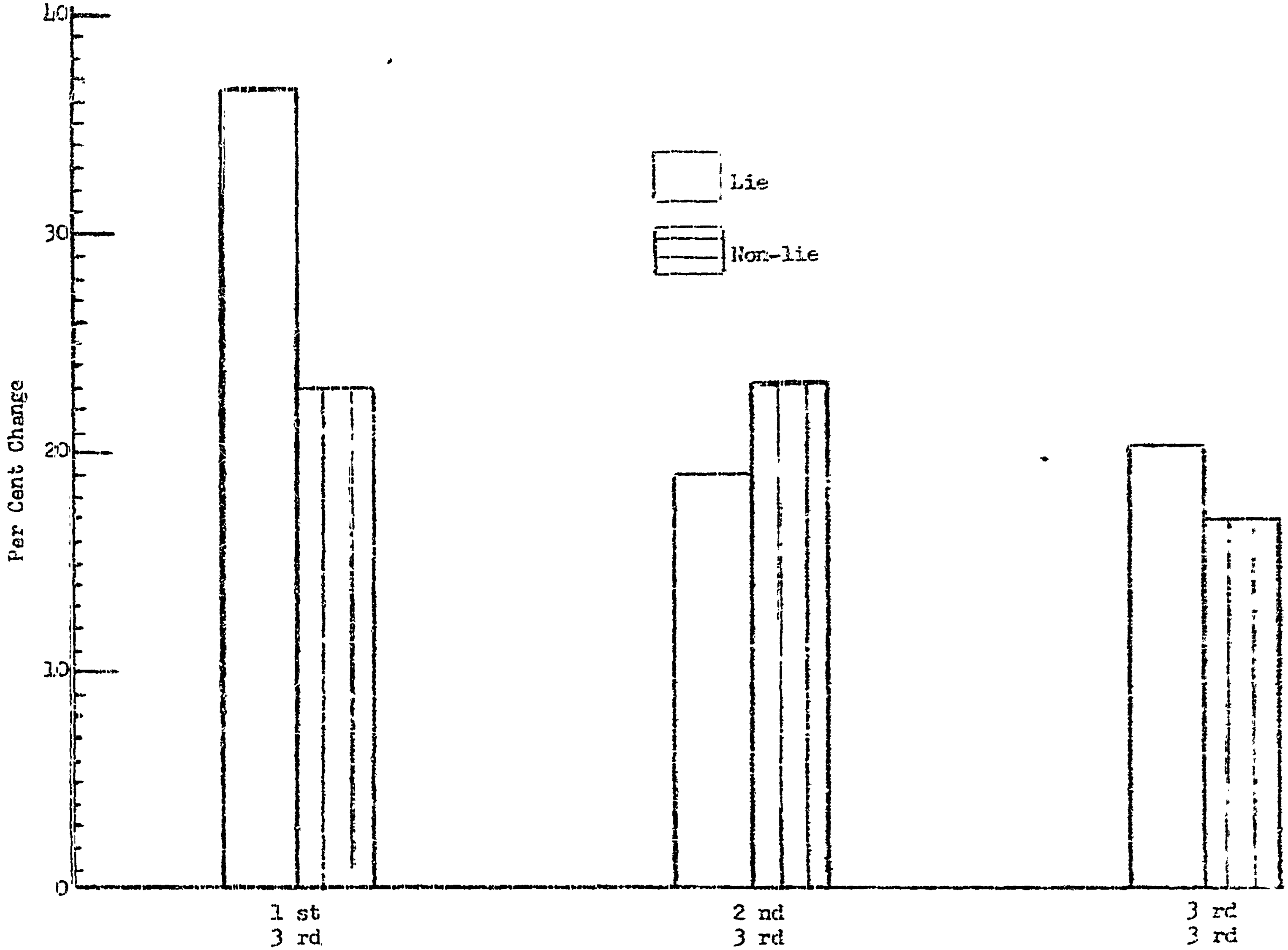


FIG. 15B G.S.R. II IN SUCCESSIVE THIRDS OF PROCEDURE 7

FIG. 16A BREATHING AMPLITUDE CHANGE FOLLOWING QUESTIONS 5-14 (PROCEDURE 6)

Measurement is Period C Minus Period A

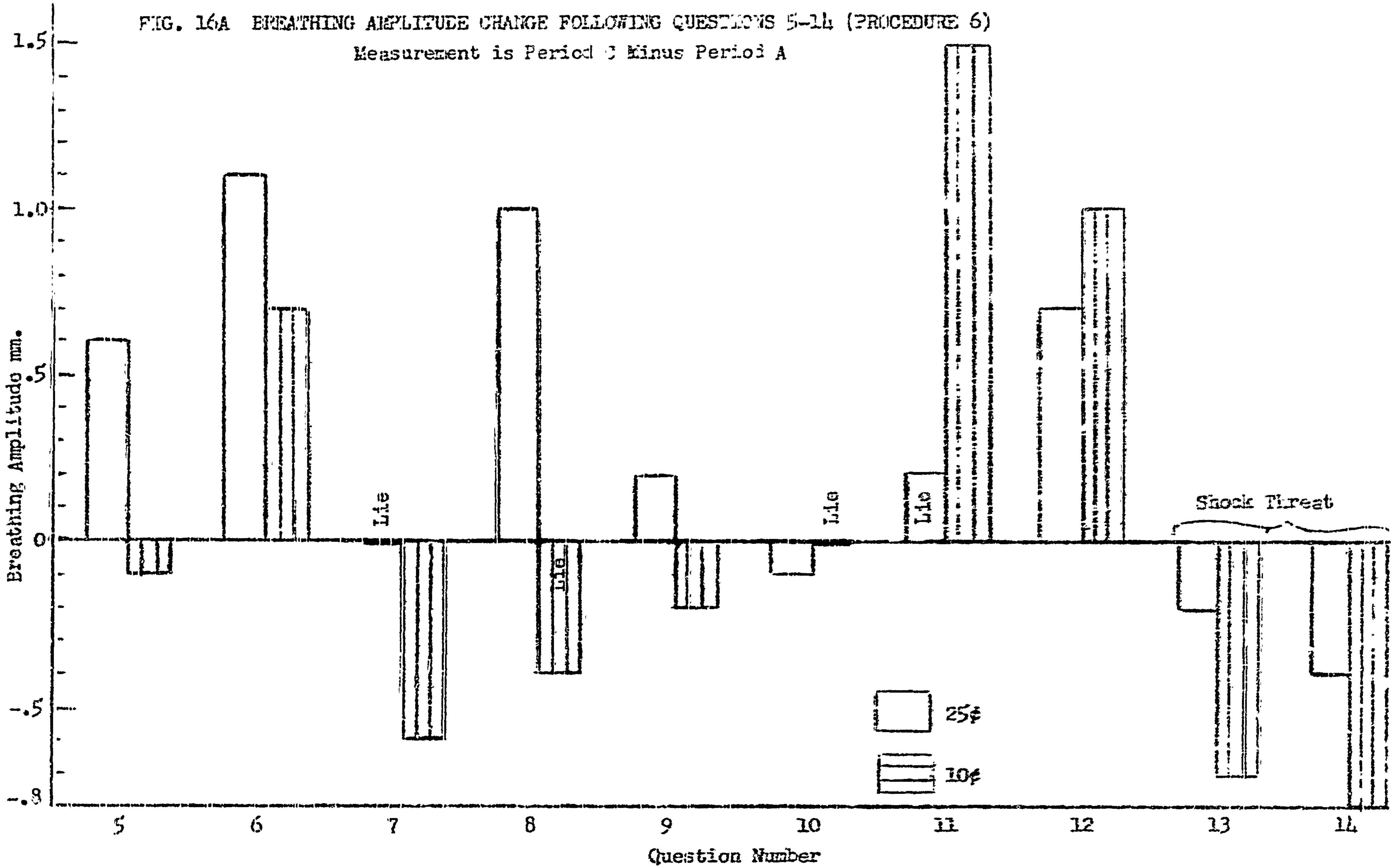


FIG. 16B VOLUME PULSE AMPLITUDE DECREASE (PROCEDURE 6)
(Pre-stimulus Minus Third Post-stimulus Measures)

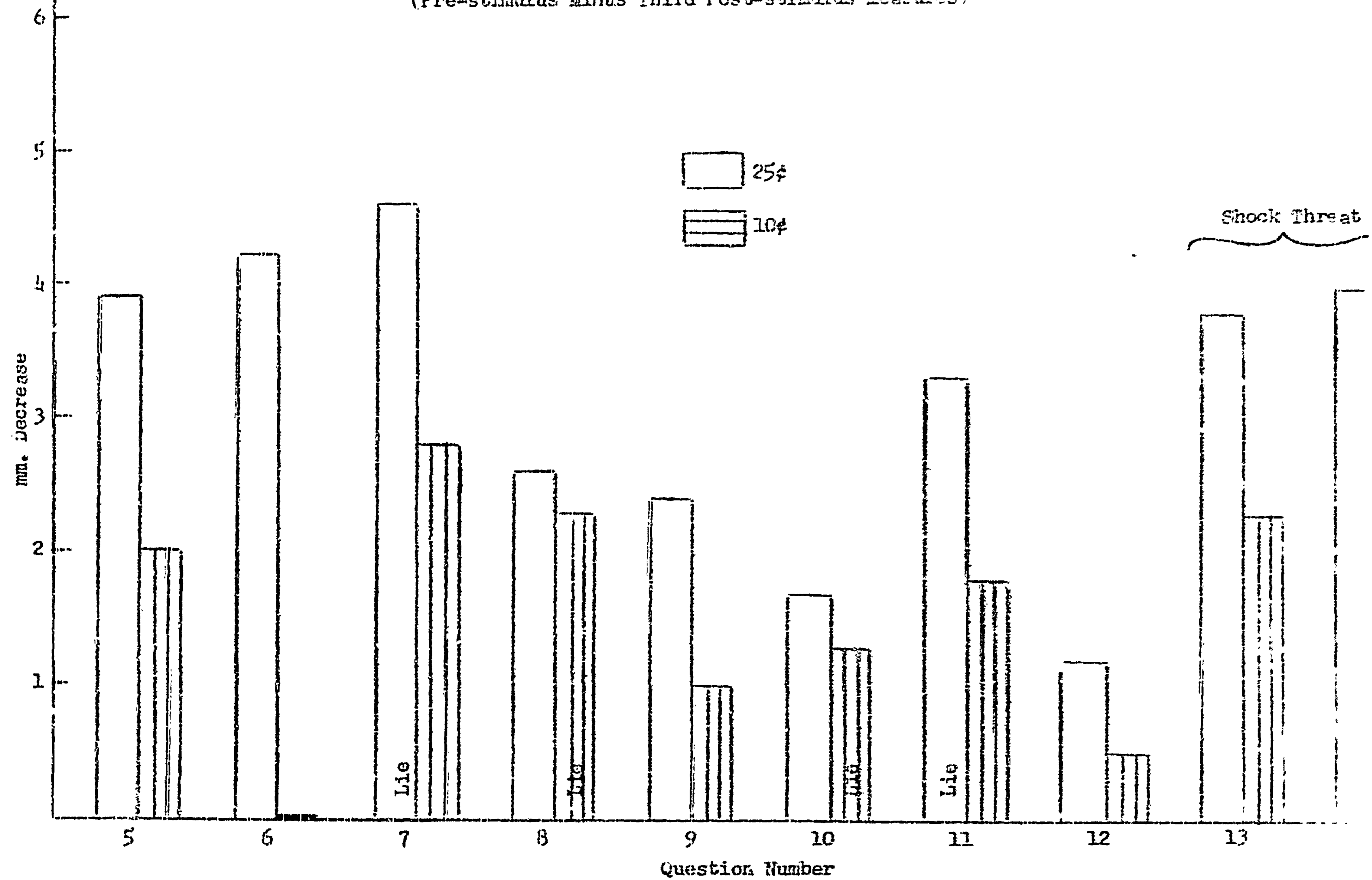


FIG. 16C SYSTOLIC BLOOD PRESSURE CHANGE (PROCEDURE 6)

$\left(\dfrac{\text{1st Post-stimulus Minus Pre-stimulus}}{\text{Pre-stimulus}} \right)$

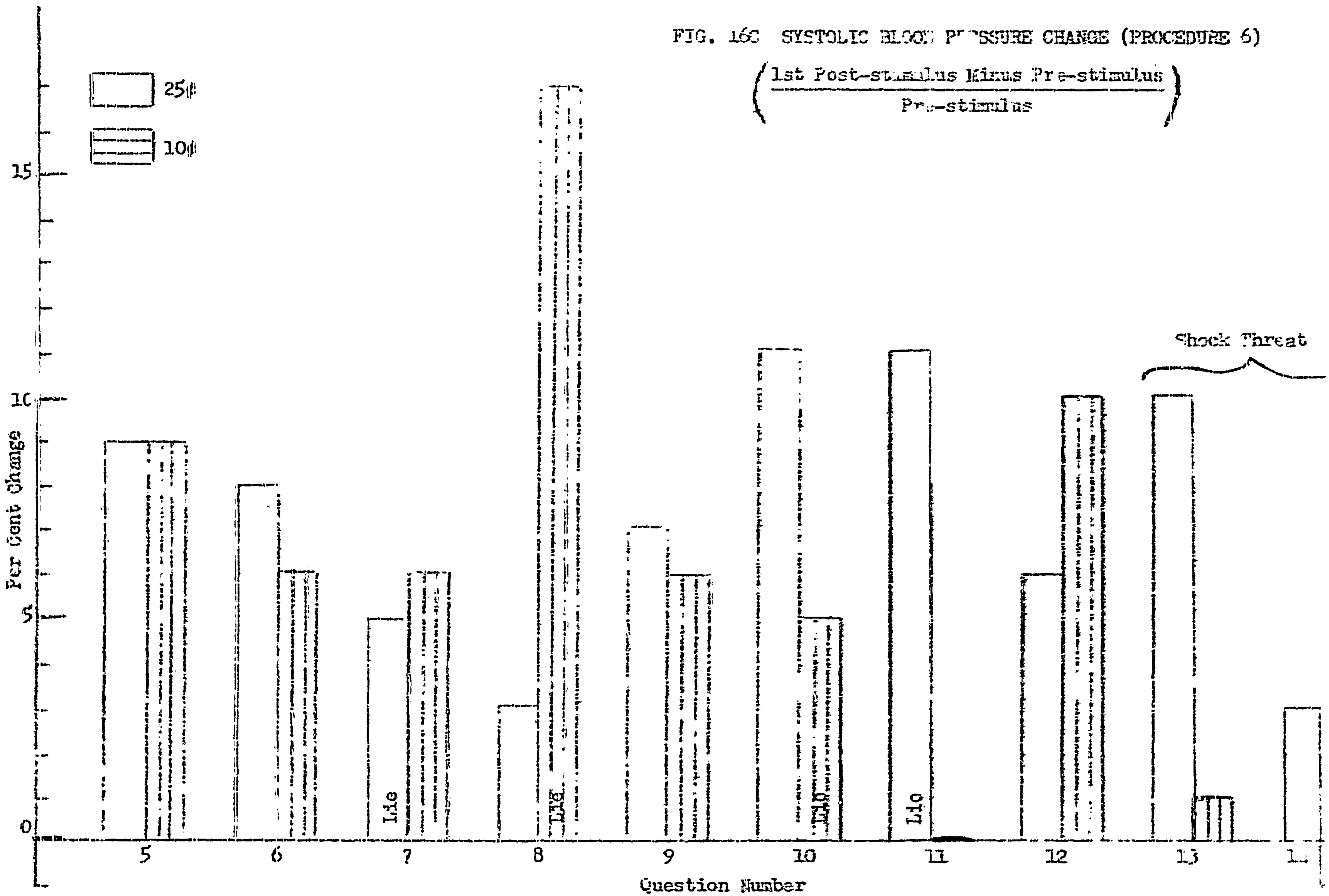


FIG. 16D INTER PULSE INTERVAL INCREASE FOLLOWING STIMULI (PROCEDURE
(Third times First Post-stimulus Measures)

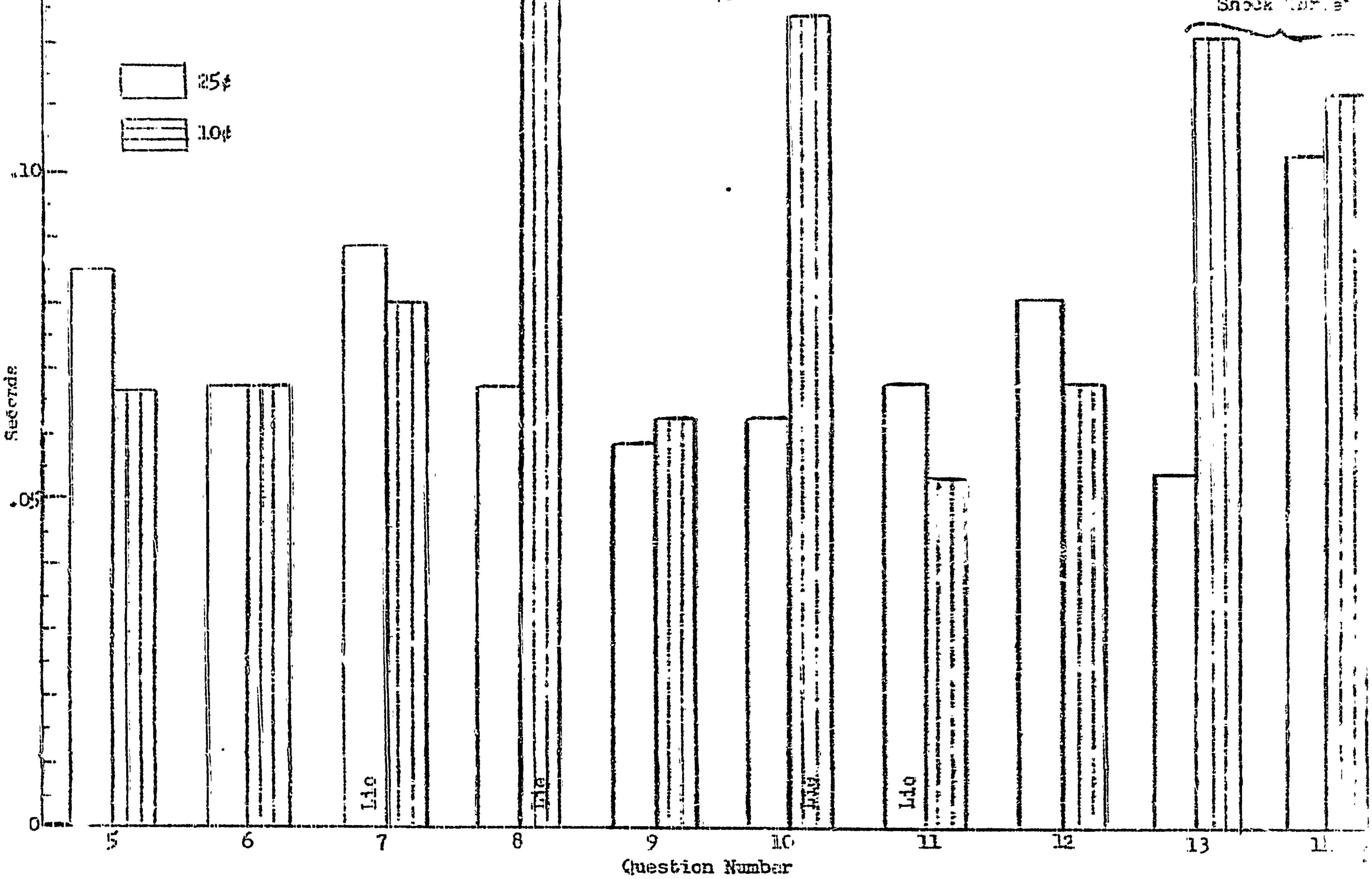


TABLE II

PER CENT DETECTION BY 1, 2 AND 3 CYCLES OF QUESTIONS

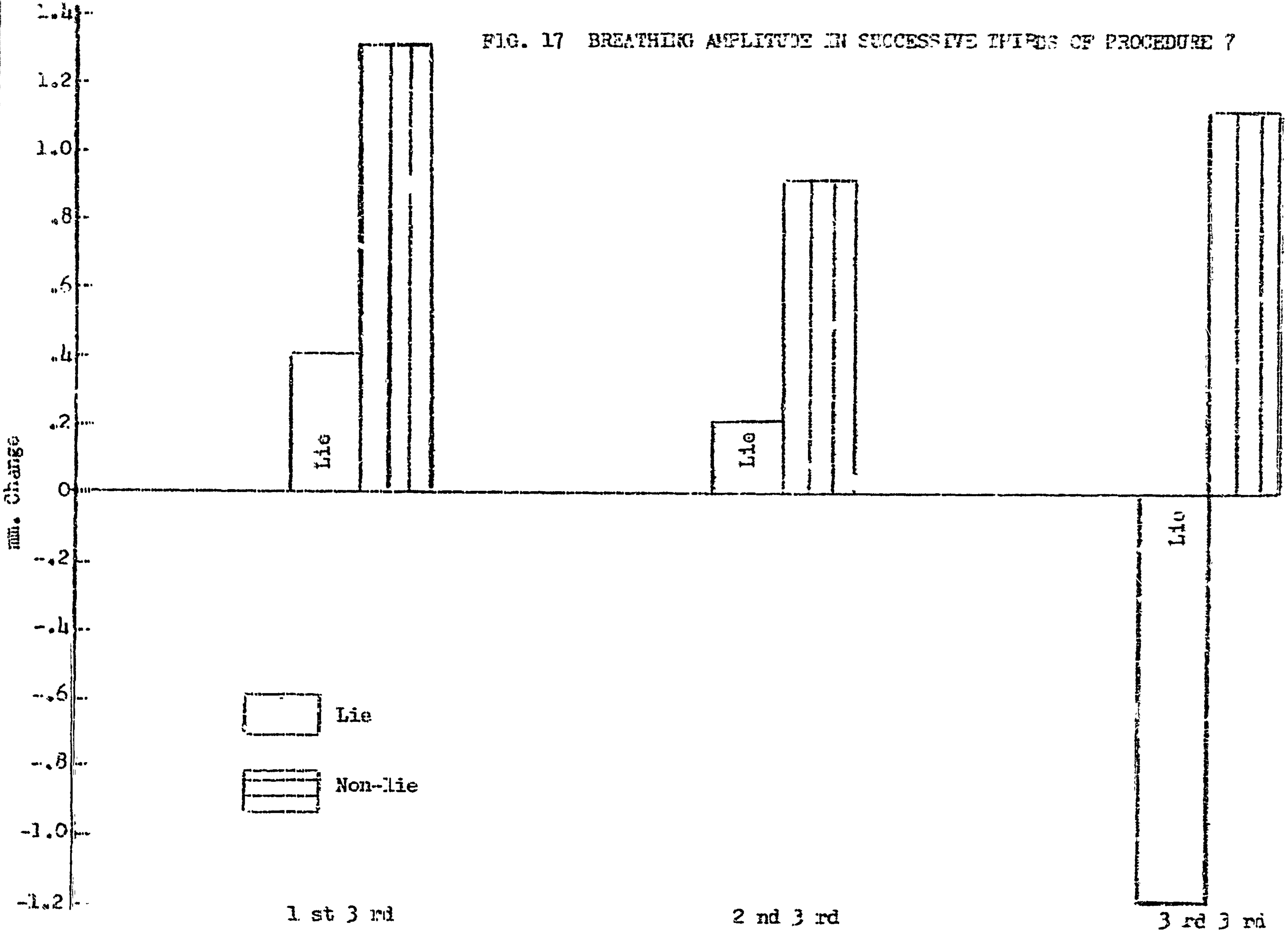
	1 Cycle	2 Cycles	3 Cycles
GSR I	65	57	60
GSR II	71	70	72
Breathing Amplitude	68	64	77
Systolic Ratio I	52	76	73
Pulse Time	64	64	64
Volume Pulse	64	77	55

(For the effects of repetition on combinations of measures see the following part of this section.)

The relative constancy of these detection percentages is similar to that found in the exploratory studies of the g.s.r. reported in a previous section. Each "cycle" of the present study, of course, included 2 lie responses and provided the comparison data for 2 non-lie responses. The conclusion from the earlier g.s.r. studies was that more than 2 presentations of critical questions in a setting does not improve detection.

In accordance with sampling theory one would, of course, expect an improvement in the reliability of measures as the numbers on which they are based increase. We doubtless have an increased reliability, but it is reliability of the wrong measure for the purpose at hand. The explanation is, no doubt, that with adaptation of responses the difference between lie responses and non-lie responses is weakened. (With complete adaptation, of course, it would be zero.) Evidence of this weakening is visible in the plots of the lie- and non-lie- responses in the three parts of Procedure 7 (Fig. 17 - 22). In breathing and blood pressure variables, repetition of the questions increases the difference between the lie and non-lie responses. In the other measures the difference diminishes to the vanishing point. There is therefore nothing to be gained by going over the questions more than twice for these measures. A combination of first measures on some variables and later measures on others might be most discriminative.

FIG. 17 BREATHING AMPLITUDE IN SUCCESSIVE THIRDS OF PROCEDURE 7



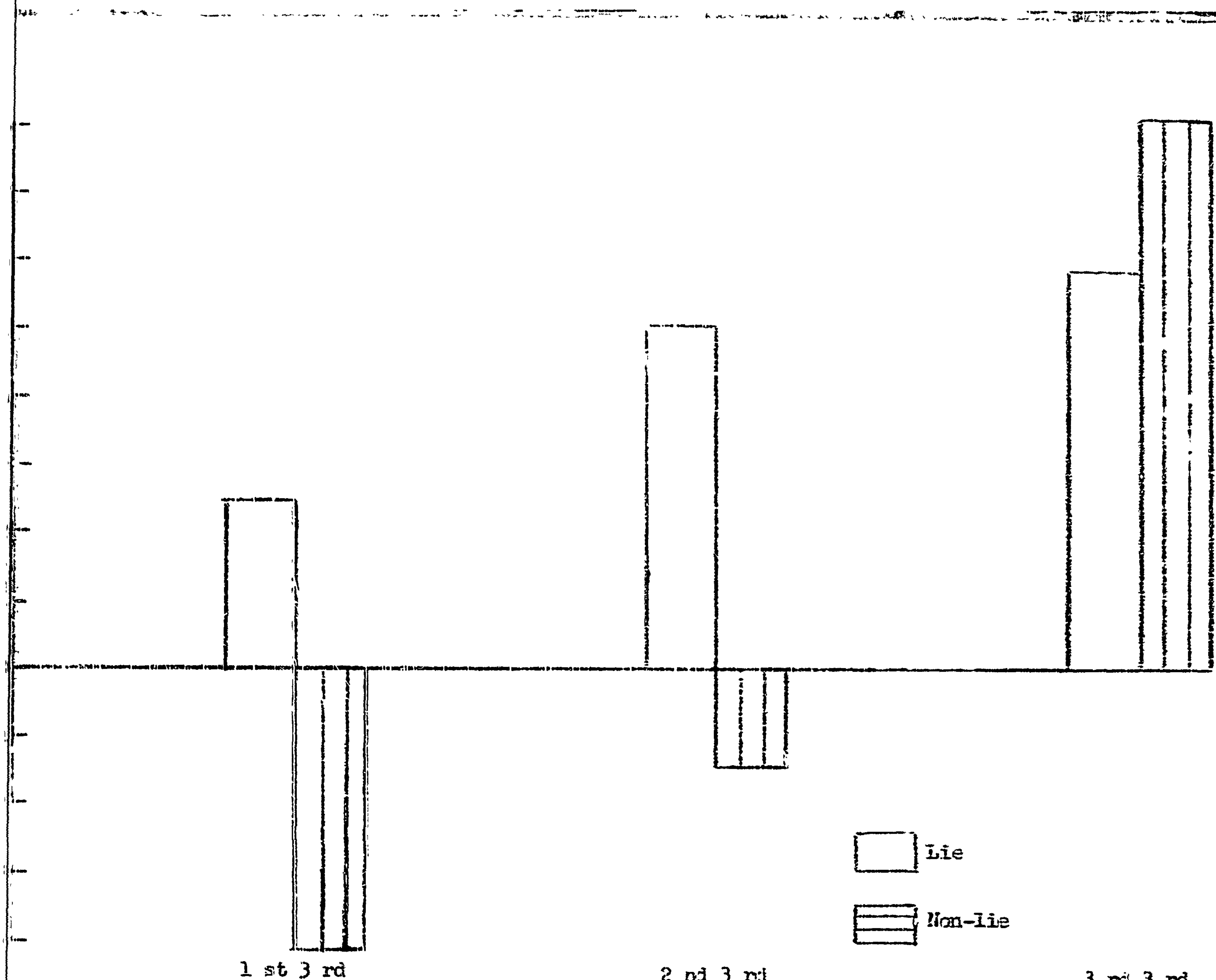
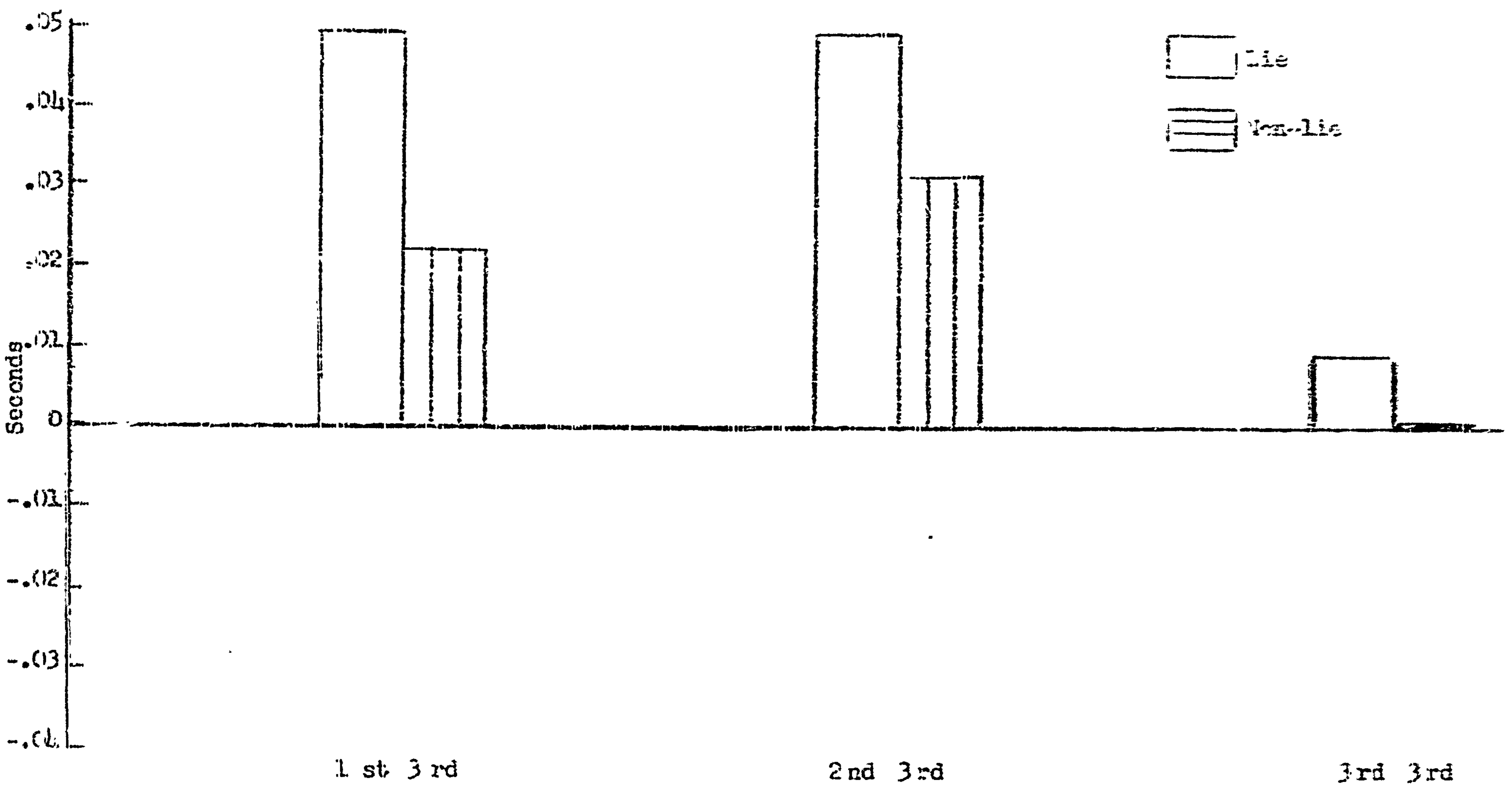


FIG. 18 SYSTOLIC BLOOD PRESSURE IN SUCCESSIVE THIRDS OF PROCEDURE 7

FIG. 19 INTER-PULSE INTERVAL CHANGES IN SUCCESSIVE THIRDS OF PROCEDURE 7



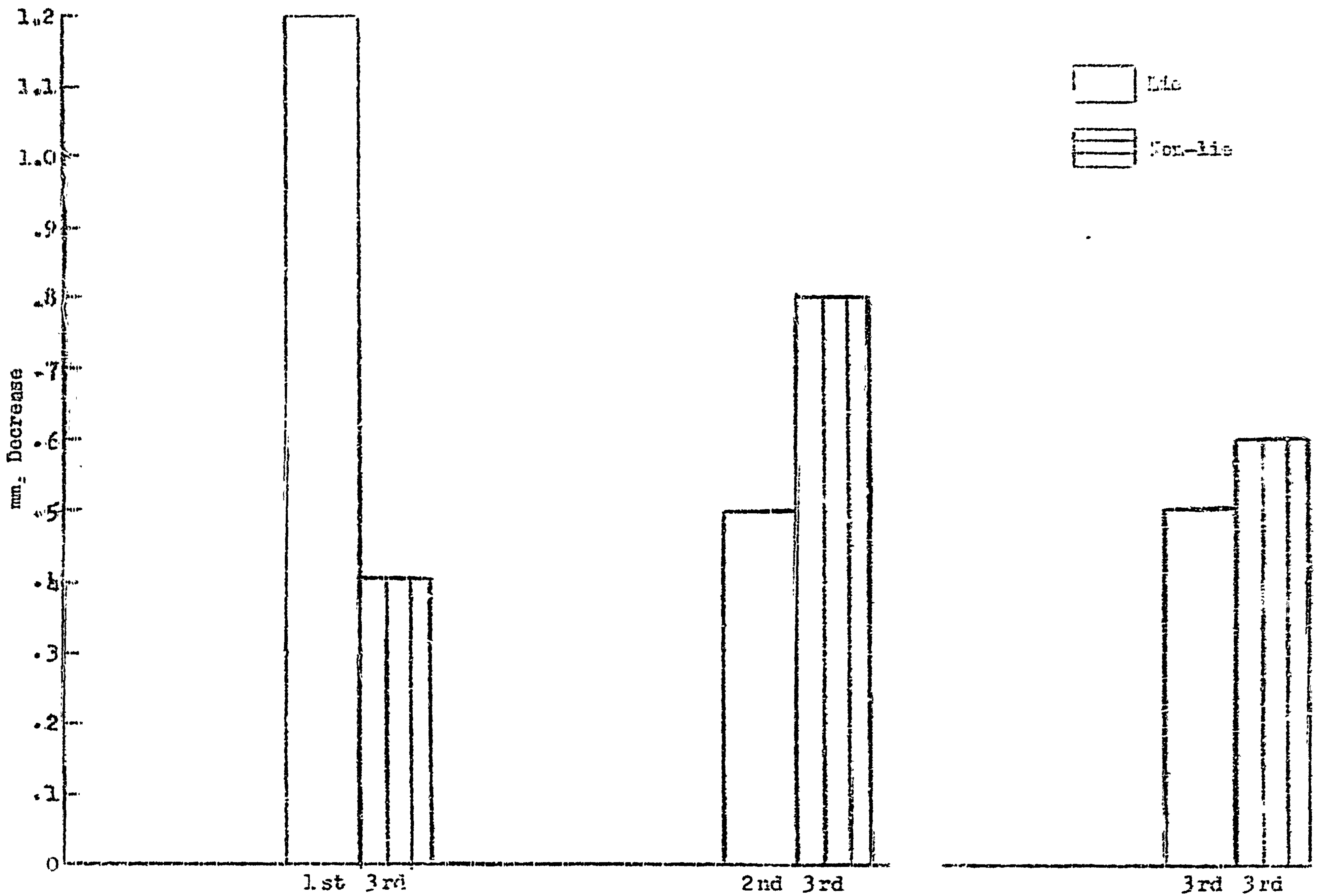
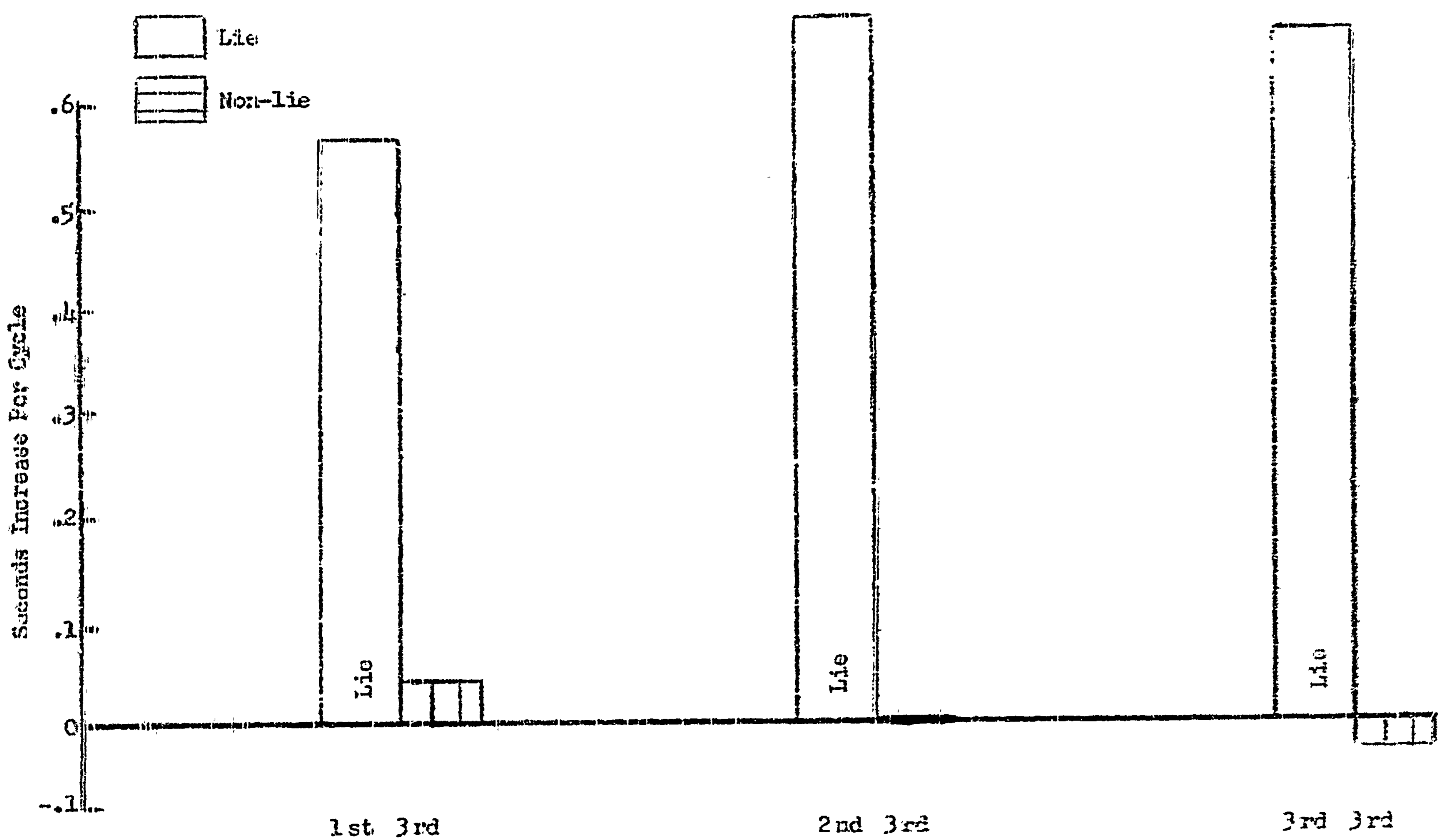


FIG. 20 VOLUME PULSE AMPLITUDE IN SUCCESSI THIRDS OF PROCEDURE 7

FIG. 21 BREATHING TIME CHANGES IN SUCCESSIVE THIRDS OF PROCEDURE 7



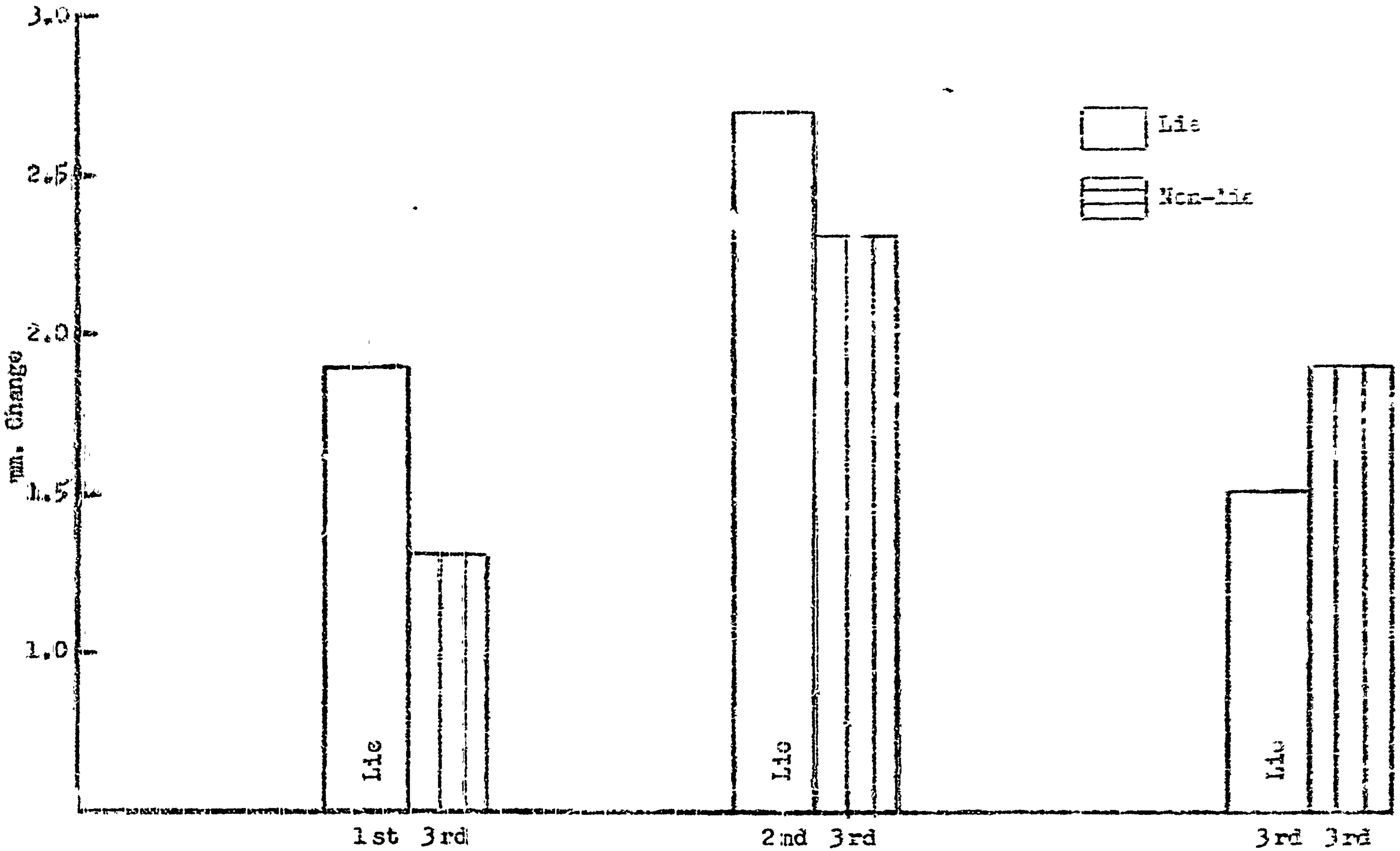


FIG. 22 PRESSURE PULSE CHANGES IN SUCCESSIVE THIRDS OF PROCEDURE 7

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CHAPTER XX

THE PROBLEM OF COMBINING VARIABLES: I. SOME RELATIONS BETWEEN LABORATORY AND FIELD DETECTION

Experiments in which deception is to be studied must have two basic situations, an experimental situation in which deception is known to occur and a control situation in which no deception occurs. Various independent variables (potential indicators of deception) may be defined and studied. In this experimental project a considerable number of such potential indicators have been considered. In the present chapter of the report, we shall first consider the implications of experimental results for the detection of deception under field conditions.

We begin with a brief consideration of some ways in which indicators of deception may behave. The simplest usable result would be the discovery of a single directly measured indicator by means of which the deception situation could be distinguished from the control situation in every experimental subject without any previous diagnosis of the subject. This state of affairs does not seem likely to occur. Another simple result would be the discovery of a single indicator on the basis of which different subjects might betray deception by reacting in opposite directions. In this case it would be possible to distinguish deception situations from control situations for any subject provided that the direction in which the subject should react was known from advance diagnostic information. When such diagnosis is necessary, the design of suitable diagnostic situations becomes an important experimental problem.

Somewhat more complex results are possible when two or more indicators are considered simultaneously. It may be the case that two indicators can be found, each of which discriminates the two situations to some extent, but neither of which is adequate for detection in itself. If a pair of indicators with these characteristics is found, it is important to determine whether the two indicators considered together yield more information than either separately. In other words, we try to combine the two indicators into a single new indicator which functions more adequately than either indicator alone. As with a single, directly measured indicator, a preliminary diagnosis may or may not be necessary for the employment of a combined indicator of this kind. If individual subjects betray deception by characteristic patterns which differ for different subjects, a preliminary diagnosis to determine the particular pattern for each individual will be necessary. It is evident that what has been said above for two variables can be extended to the simultaneous consideration of more than two variables.

Finally, it may be the case that no single variable nor combination of variables can be found which makes it possible to distinguish the two situations. This needs no further comment. Before proceeding to a discussion of combining indicators we take up a few general considerations. In the laboratory, a knowledge of the particular questions on which lies occurred is available. Even if this knowledge is not used, the experimenter does know that lies occur on some questions and not on others. In these respects the laboratory situation differs markedly from that in the field where any subject may or may not lie to any or all questions. This means that the simple question-by-question comparisons made in the laboratory studies are of only partial relevance for the situation in the field.

It would be possible to obtain perfect classification of lies and truths in the laboratory situation by methods which are completely inadequate in the field. This possibility occurs because in field applications, comparisons between questions neither of which evokes a lie must be made. To see this point more clearly, we consider some data from one of our g.s.r. experiments, and append a few remarks to clarify some of the implications of the important difference between the two situations.

In the experiments we have performed a sequence of questions was asked and it was known in advance that the subject would lie to some subset of questions in the sequence. In the field situation a sequence of questions is asked and on any given question it is not known whether the subject will lie or not; he may lie to all questions and he may lie to none. For purposes of further discussion we include here a portion of the data obtained for liars in experiments described in Chapters II and III, Part I, together with the expected results on a group of 40 non-liars; in the earlier chapters the data have not been worked up in quite this form. For our present purposes, we ignore whatever unreliability may be present in the data, assuming that the frequencies we observe are stable expected frequencies.

TABLE I

EXPECTED FREQUENCIES WITH WHICH POSITIVE AND NEGATIVE DIFFERENCES BETWEEN AVERAGE LYING AND NON-LYING G.S.R. DEFLECTIONS FOR 33 LIARS AND 40 NON-LIARS

	−	+
Liars (Observed)	2	31
Non-liars (Hypothetical)	20	20

From Table I we see that a simple classification rule with the dividing point at zero would give a fairly good classification of the liars. Only two errors would be made in 33 cases. But on the non-liars the picture is different; half of these would be misclassified. Thus, out of the 73 cases presented in Table I, 22 errors of classification would result. The number of classification errors on non-liars could be cut down by dichotomizing at some positive value instead of zero. It is readily seen that the selection of a large negative value as the point of dichotomy would yield misclassifications of all non-liars and the selection of a large positive value would result in the misclassification of all liars. As the point of dichotomy was moved from a large negative to a large positive value, an optimum position could usually be found which would result in either a smaller number or a smaller proportion of total misclassifications than any other point. (It should be noted that, if one kind of classification error is considered more serious than the other, different weights could be assigned to the two types and an optimal point would be found which minimized the weighted sum of the errors.) For a simple classification procedure of this kind, such an optimal point would always be desirable but, even at the optimal point, the number or classification errors might be intolerably large. We shall consider how the number of these errors can be systematically diminished.

To facilitate the discussion, we introduce some data on 26 liars from the cardiovascular procedure together with some hypothetical data on 40 non-liars. Again, we ignore the unreliability of the data merely for purposes of exposition. (In the hypothetical portion of Table II, it is assumed that the two indicators are uncorrelated. This assumption is false and its implications will be indicated below.) We see from Table II that, if classifications are based on a simple dichotomy about zero approximately 1/3 of the liars and 1/2 of the non-liars would be incorrectly classified on the basis of heart-rate. The corresponding figures for blood pressure are 5/13 and 1/2 respectively. Neither classification is very efficient with this crude dichotomy. Suppose we now base our classification on both variables in the following way: Subjects exhibiting positive blood pressure differences and negative heart rate differences are non-liars. Subjects with these signs reversed are liars. Subjects for whom both signs are in the same direction are classified as undetermined -- more information is necessary before they can be definitely classified. With this procedure only 1/26 of the liars and 1/4 of the non-liars are definitely misclassified, so a considerable gain results from the use of the two variables. If the variables were negatively correlated there would still be a gain but for the non-liars it would not be so large as in the uncorrelated case. Accompanying this gain, of course, there is a loss; the classification of slightly over half the subjects is undetermined. The situation with respect to unclassified subjects can be improved by repeating the operations. Liars should stay in the "lying category" more consistently than non-liars. The remarks made about optimum points with the single variable in Table I apply again to the double-variable classification of Table II.

We see, from this example, the gains in classification that result from the utilization of additional information. The use of a crude dichotomy is an oversimplification which facilitates description of the problem, but which does not reveal the full power of pattern analysis. The statistical methods of discriminant functions can be used to find the patterns of variables which best differentiate liars from non-liars and to provide optimum points for the classifications. With these more refined techniques the problem of undetermined cases is by no means as important as in the scheme of dichotomization carried out above. Since the computational techniques are laborious and time-consuming, discriminant analyses have been made only on the data from certain selected experiments involving muscle action potentials with suggestive, but not yet conclusive, results. The methods used and results obtained are described in Chapters VII and VIII, Part I.

TABLE II

FREQUENCIES OF POSITIVE AND NEGATIVE SIGNS FOR THE LYING-NON-LYING DIFFERENCES IN HEART RATE AND BLOOD PRESSURE FOR 26 LIARS AND 40 NON-LIARS

Liars (observed)

	Heart rate −	Heart rate +	
Blood pressure +	1	9	10
Blood pressure −	8	8	16
	9	17	26

Non-liars (hypothetical)

	Heart rate −	Heart rate +	
Blood pressure +	10	10	20
Blood pressure −	10	10	20
	20	20	40

CHAPTER XXI

THE PROBLEM OF COMBINING VARIABLES: II. RESULTS FOR PROCEDURES 6 AND 7

We consider data in which a value for each of m indicators has been obtained for each member of a set of n individuals. It may be the case that, although no single variable provides some desired classification of the individuals, some combination of the variables will do so. There are many ways in which the variables can be combined. For the detection of deception we wish to classify a given individual in a specific situation as either a liar or a non-liar. When indicators are to be combined, it would be desirable to find that combination which minimizes the number of errors of classification. Unfortunately this cannot easily be done in any direct manner.

If all possible ways of combining indicators and all possible criteria for a "good combination" are considered it can be shown that in some cases insoluble problems result and in other cases the solutions which exist are very difficult to achieve. By restricting our consideration to linear combinations of the indicators we can select a criterion for a "best combination" for which the mathematical solution can easily be found. Whenever the statistical distributions of the individual indicators behave in a reasonably decent manner the solution which is obtained can be expected to come reasonably close to minimizing the expected number of misclassifications.

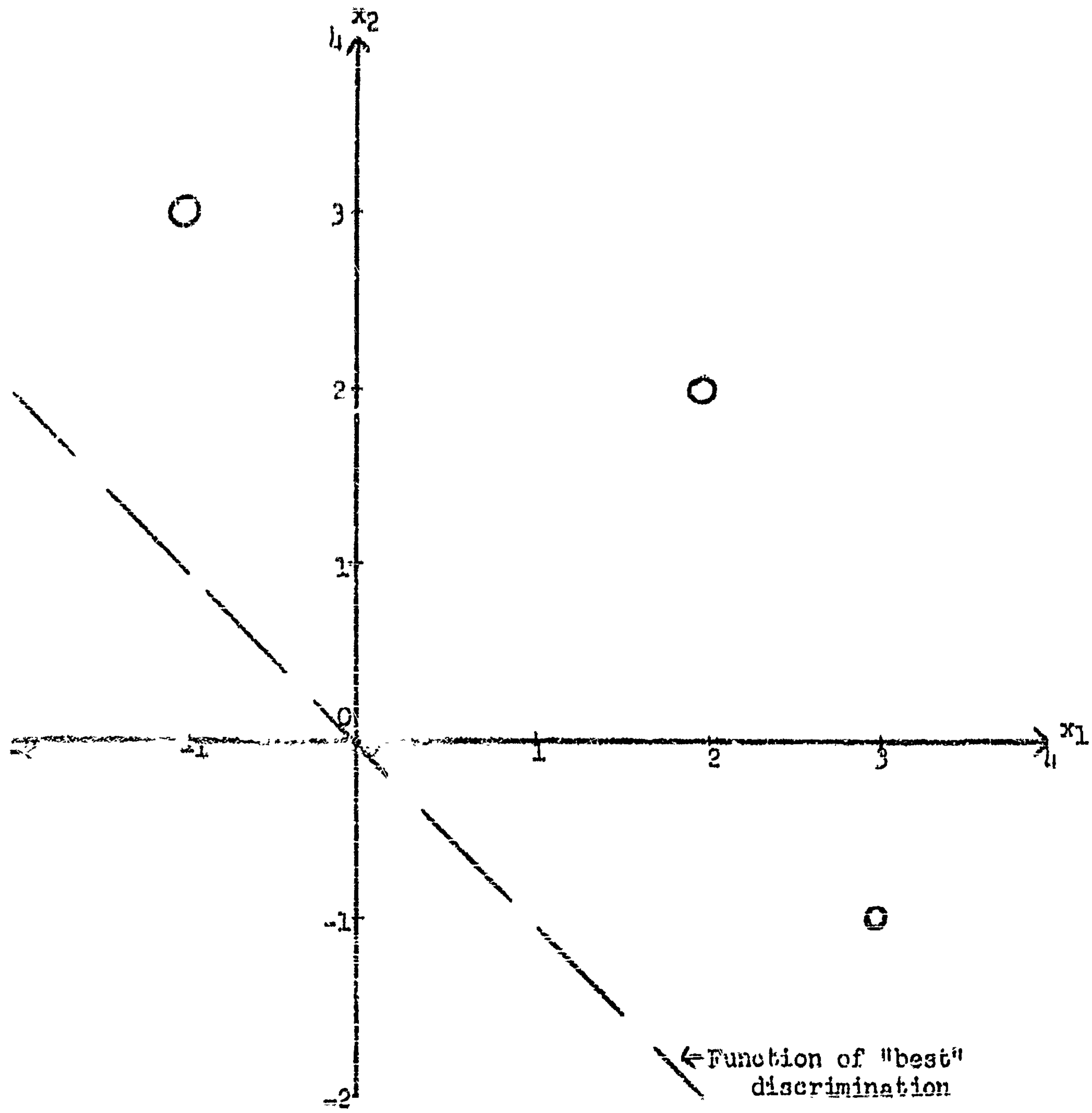
The problem of combining indicators as we have posed it in interpreting our data is closely related to a corresponding problem posed by the taxonomist and solved by means of discriminant functions. The solution is given by Hoel (2). A similar solution for the deception data is given in a mathematical appendix following this section. To illustrate the meaning of this solution we shall consider a highly simplified example.

An Example

The situation to be described here parallels the situation in our deception data. We imagine that we have asked two questions of each of three subjects and that each subject lies to the first question and answers the second question truthfully. It is expected that lying should be represented by an increased value of both indicators, but the results are not in harmony with this anticipation. We let x_1 be the increase in the first indicator from the non-lying to the lying situation and x_2 the corresponding increase in the second indicator. In Fig. 1 are given the presumed results on the three subjects. From Fig. 1 we note the following features. The average increase in each indicator is $+\frac{4}{3}$ units, showing some discriminative power in the individual indicators. Each of two subjects exhibits an increase on one indicator and a decrease on the other so that, on the basis of sign alone, these two subjects are cases of indeterminate classification. The third subject exhibits an increase on both indicators. We seek to combine the two indicators into a single variable z which removes the indeterminacy, considering only linear combinations of the form:

(1) $z = \lambda_1 x_1 + \lambda_2 x_2$

FIG. 1 SCHEMATIC EXAMPLE FOR COMBINING INDICATORS



The "best combination" is given by those values of λ which minimize the ratio of the square of the mean value of z to the variance of z. From equation (12) of the appendix, taking C equal to one, we have the two equations to be solved for λ:

$$(2)\quad s_{11}\lambda_1 + s_{12}\lambda_2 = \bar{x}_1$$

$$s_{12}\lambda_1 + s_{22}\lambda_2 = \bar{x}_2$$

Using equation (5) of the appendix and the data of the present example, we obtain:

$$s_{11} = \frac{1}{3}\left[(-1)^2 + (3)^2 + (2)^2\right] - \frac{16}{9} = \frac{47}{9}$$

$$(3)\quad s_{12} = \frac{1}{3}\left[(-1)(3) + (-1)(3) + (2)^2\right] - \frac{16}{9} = \frac{25}{9}$$

$$s_{22} = \frac{1}{3}\left[(3)^2 + (-1)^2 + (2)^2\right] - 1 = \frac{47}{9}$$

With these values (2) becomes:

$$(4)\quad \begin{aligned} 47\lambda_1 - 25\lambda_2 &= 9 \\ -25\lambda_1 + 47\lambda_2 &= 9 \end{aligned}$$

Equations (4) can be solved directly by substitution for λ_1 and λ_2. The solution is $\lambda_1 = \lambda_2 = \frac{9}{22}$. If we had taken c as 22/9, we should have obtained

(5) $\lambda_1 = \lambda_2 = 1$ and this solution is more convenient to use. The fact that we can make an arbitrary choice of the constant c reflects merely that we need only relative values, not absolute values, to make our classification.

In view of (1) and (5), we take as our criterion variable

$$(6)\quad z = x_1 + x_2$$

For our three subjects, the values of z calculated by means of (6) are +2, +2, and +4. Since these are all positive, the classification is correct in all three cases. The mean of these three values of z is $\frac{8}{3}$ and the variance is $\frac{4+4+16}{3} - \left(\frac{8}{3}\right)^2 = \frac{8}{9}$. Hence the ratio of the mean squared to the variance is $\left(\frac{8}{3}\right)^2 / \frac{8}{9} = 8$.

It should be noted that there are other sets of weights which would also lead to correct classifications in this example. We may, for example, take $\lambda_1 = 1$, $\lambda_2 = 2$, and write:

$$(7) \quad z = x_1 + 2x_2$$

For the three subjects we obtain values of 1, 5, and 8 for z; these are again all positive. Their mean is $\frac{14}{3}$ and their variance is $\frac{1+25+64}{3} - (\frac{14}{3})^2 = \frac{74}{9}$. The ratio of the mean squared to the variance of these measures is $(\frac{14}{3})^2 / \frac{74}{9} = \frac{196}{74} = 2.65$. From the smaller value of this ratio we should not expect as sharp a discrimination using (7) as we could obtain using (6). To put the matter another way, the computational technique developed in the appendix and used in obtaining (6) achieves a sharp discrimination because it leads at one time to a set of relatively homogeneous measures whose mean is relatively large.

We may further point out certain differences between the field situation and the laboratory experiments. In the data discussed below as well as in the simple example given above, it is known that both lying and truthtelling occurred. In the field situation this restriction on the problem is not present: values of z obtained from two non-lying questions would be equally likely to be positive and negative under the influence of chance effects.

Combination of Variables for Lie Detection

The following indicators from Procedure 6 gave evidence individually of discriminative power: The two measures of g.s.r., systolic pressure, pulse pressure, volume pulse amplitude, pulse rate time, and pulse time. These indicators are defined more precisely in a previous section of this report.

In the present section, results of the study of their predictive power in combination will be reported.

It will be recalled that, in Procedure 6, questions relative to the denominations of money taken by the subjects (nickels, dimes, quarters, half-dollars) were asked; under the conditions of the experiment each subject lied to a certain subset of the questions. Because of the presence of sequential effects in the records only subjects who lied on the questions involving dimes and quarters were used in the combination of indicators. There were 44 such subjects from whom adequate data were available. For these subjects, the eight indicators mentioned above were combined by the methods of the previous section. The weights obtained for each variable are given in Table I.

TABLE I

Indicator	Weight
G.S.R. I	361.3
G.S.R. II	411.4
Systolic pressure	235.7
Pulse pressure	-1.0
Volume pulse amplitude	-3.6
Pulse time	-15.6
Pulse rate time	15.1

The weighted linear sum of the lying-non-lying differences on these measures as they were read from the records was taken as an indicator for classification. The frequency distribution of this indicator is presented as a histogram in Fig. 2.

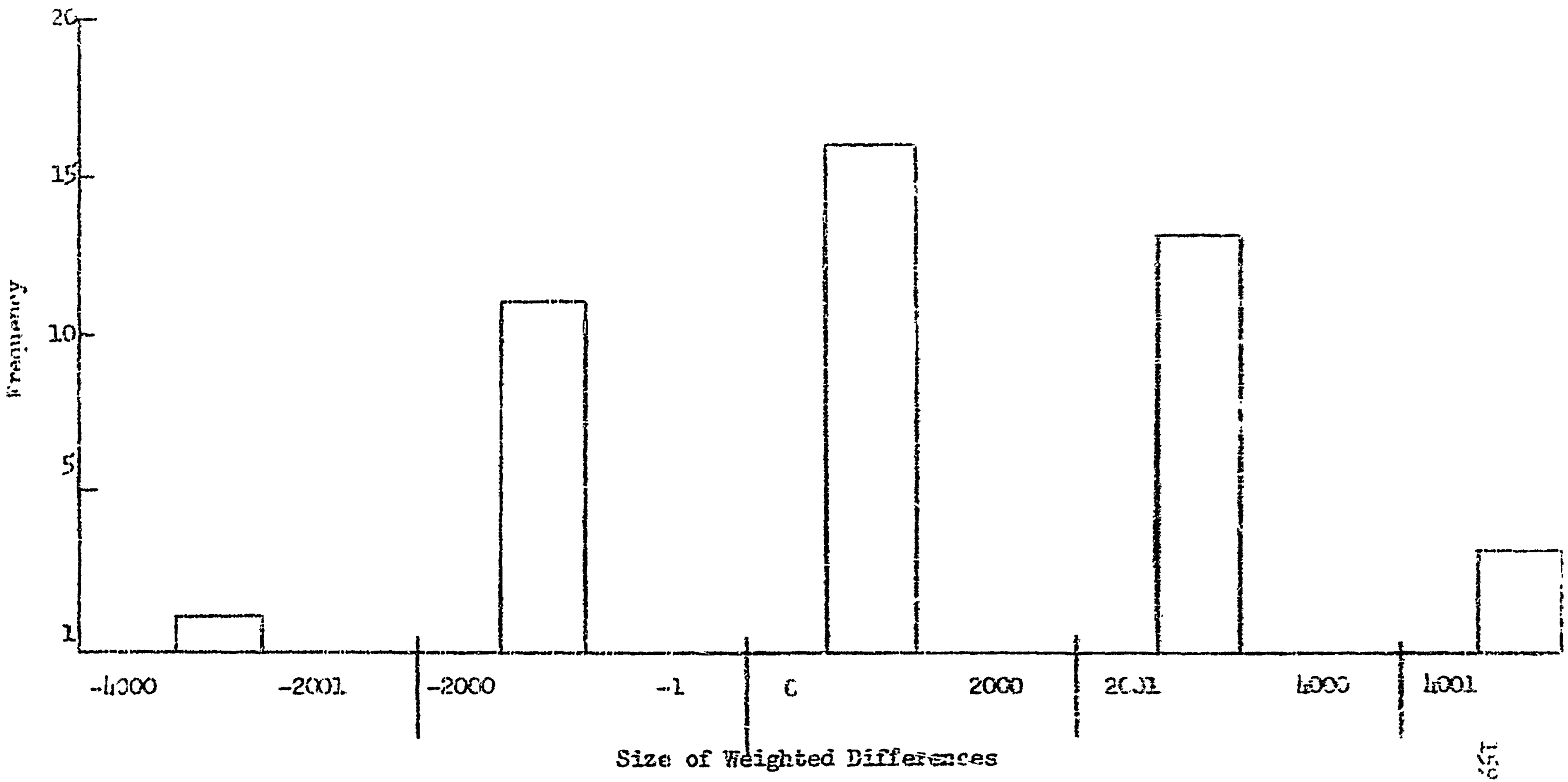
For the group of subjects run in Procedure 6 73% of the lies are correctly classified by means of the combinative indicator. This figure is rather disappointing and one could do about as well with one of the g.s.r. measures alone.

For the 22 subjects run through a roughly equivalent experimental routine in Procedure 7 the weights obtained from Procedure 6 were applied to the new data for a check. On this new group 84% of the lies were correctly classified, a figure that would seem to be accidentally high since the combinative indicator did not work this well on the data from which the weights were derived.

Various non-linear combinations, selected more or less at hazard, were tried. These yielded percentages of correct classifications between 80% and 90% and should be explored further.

It does not seem to the writer that these values of 80-90% correct classifications of liars can be much improved until techniques and procedures are found to increase the reliability of the individual measures. The question of reliability is even more crucial in the field situation where the possibility that no lies are told must be dealt with.

FIG. 2 FREQUENCY DISTRIBUTION FOR LIE-NON-LIE DIFFERENCE IN COMBINED INDICATOR



Appendix

Derivation of the equation:

We consider measurements of m variables on n subjects and let x_{ij} represent the measure of the j^{th} variable obtained on the i^{th} subject and let $\bar{x}_j$ represent the mean of the j^{th} variable over the group of subjects. For each subject and any choice of λ_j we obtain a measure which is a linear combination of the measures directly obtained on that subject according to (1):

$$(1)\quad z_i = \sum_{j=1}^{m} \lambda_j x_{ij}$$

The mean value of the z's is given by (2):

$$(2)\quad \bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{m}\lambda_j x_{ij} =$$

$$\frac{1}{n}\sum_{j=1}^{m}\sum_{i=1}^{n}\lambda_j x_{ij} = \sum_{j=1}^{m}\lambda_j\bar{x}_j$$

whence

$$(3)\quad \bar{z}^2 = \left(\sum_{j=1}^{m}\lambda_j\bar{x}_j\right)^2 = \sum_{j=1}^{m}\sum_{k=1}^{m}\lambda_j\lambda_k\bar{x}_j\bar{x}_k$$

The variance of the z's is given by (4):

$$(4)\quad \sigma_z^2 = \frac{1}{n}\sum_i (z_i-\bar{z})^2 = \frac{1}{n}\sum_i\left[\sum_j\lambda_j(x_{ij}-\bar{x}_j)\right]^2$$

$$= \frac{1}{n}\sum_i\sum_j\sum_k\lambda_j\lambda_k\,(x_{ij}-\bar{x}_j)\,(x_{ik}-\bar{x}_k)$$

$$= \sum_j\sum_k\lambda_j\lambda_k\,s_{jk}\text{ , where}$$

$$(5)\quad s_{jk} = \frac{1}{n}\sum_i(x_{ij}-\bar{x}_j)\,(x_{ik}-\bar{x}_k)$$

$$= \frac{1}{n}\sum_i x_{ij}x_{ik} - \bar{x}_j\bar{x}_k\text{ , the numerator occurring in the}$$

ordinary formula for the correlation coefficient of x_j and x_k.

We next define

(6) $U = \frac{\bar{z}^2}{\sigma_z^2}$, where $\bar{z}^2$ and σ_z^2 are given by (3) and (4) and seek values of λ which maximize U. In other words, we desire m values λ_r such that

$$(7) \quad \frac{\partial U}{\partial \lambda_r} = 0, \; r = 1, 2, \ldots, m.$$

It is easily shown by elementary formulas of differentiation that (7) implies (8):

$$(8) \quad \frac{\partial \sigma_z^2}{\partial \lambda_r} = \frac{1}{U} \frac{\partial \bar{z}^2}{\partial \lambda_r}, \; r = 1, 2, \ldots, m.$$

From (3) and (4), we see that

$$(9) \quad \frac{\partial \bar{z}^2}{\partial \lambda_r} = 2\bar{x}_r \sum_{j=1}^{m} \lambda_j \bar{x}_j \quad \text{and}$$

$$(10) \quad \frac{\partial \sigma_z^2}{\partial \lambda_r} = 2\sum_{j=1}^{m} \lambda_j s_{jr}$$

Substitution of (9) and (10) into (8) gives (11):

$$(11) \quad \sum_{j=1}^{m} \lambda_j s_{jr} = \frac{\sum_{j=1}^{m} \lambda_j \bar{x}_j \bar{x}_r}{U}, \; r = 1, 2, \ldots, m.$$

We next note that $\frac{\sum_{j=1}^{m} \lambda_j \bar{x}_j}{U}$ is independent of r and hence can be given any constant value c in the m equations of (11). Then (11) becomes (12):

$$(12) \quad \sum_{j=1}^{m} \lambda_j s_{jr} = c\, \bar{x}_r, \; r = 1, 2, \ldots, m.$$

Equations (12) are seen in view of (5) to be formally identical with the equations for the non-standardized regressions in multiple regression problems (Guilford, 1). They can be written so that the Doolittle technique can be employed to solve for the m values of λ.

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1. Guilford, J. P. *Psychometric Methods.* New York: McGraw-Hill, 1936.

2. Hoel, P. G. *Introduction to Mathematical Statistics.* New York: Wiley, 1947.

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